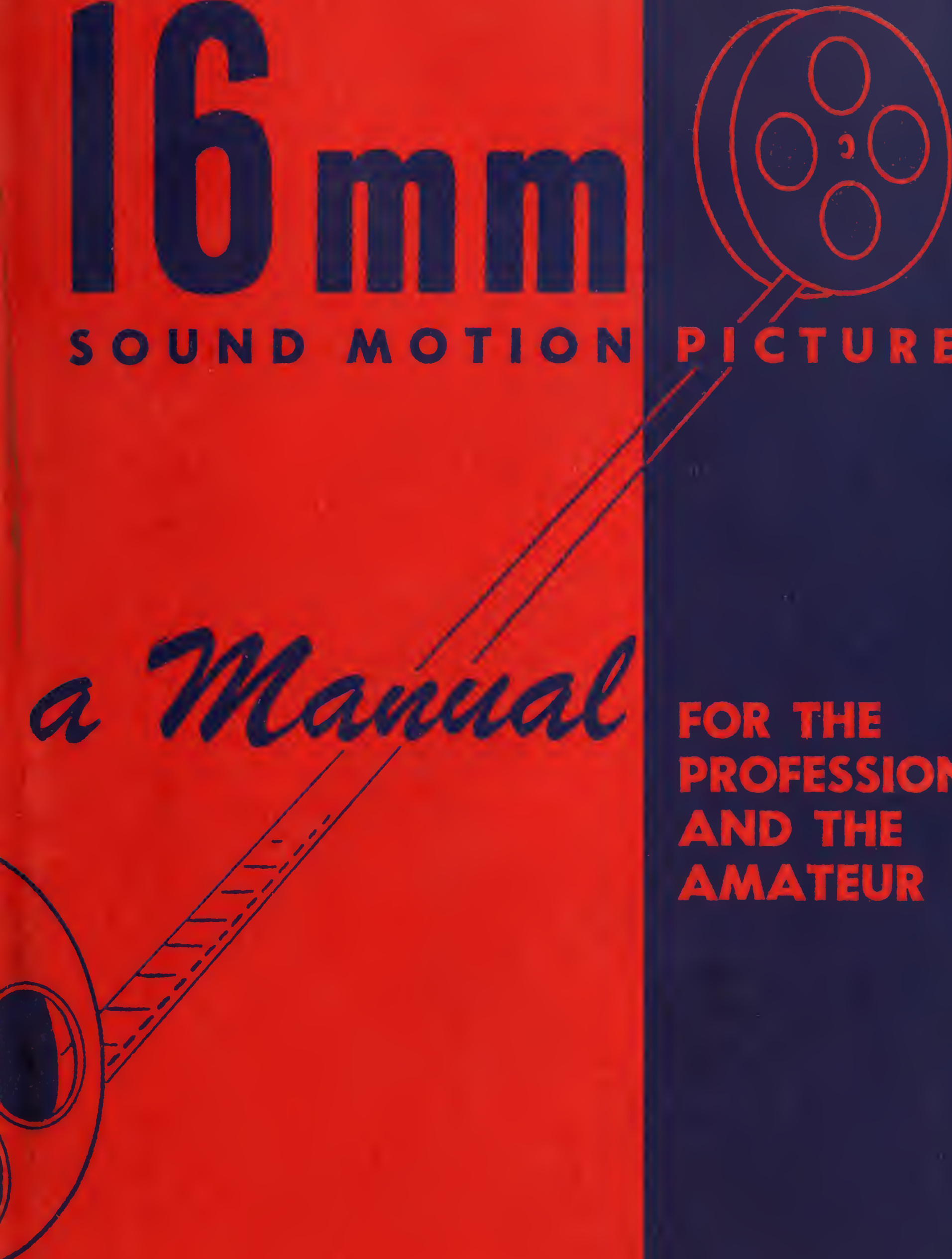
W. H. OFFENHAUSER, Jr.

16mm SOUND MOTION PICTURES



a Manual

FOR THE PROFESSIONAL AND THE AMATEUR

INTERSCIENCE PUBLISHERS

65

To Bob,

March 7, 1955

My bounty is as boundless as
the sea
My love as deep; the more I
give to thee
The more I love, for both
are infinite.

Audrey

16-Mm Sound Motion Pictures

A Manual for the Professional and the Amateur

16-Mm Sound Motion Pictures

A MANUAL

for the Professional
and the Amateur

WILLIAM H. OFFENHAUSER, Jr.
Andre DeBrie of America, Inc., New York

INTERSCIENCE PUBLISHERS, INC., NEW YORK
INTERSCIENCE PUBLISHERS LTD., LONDON

To My Wife

First printing, 1949
Second printing (with revisions), 1953

INTERSCIENCE PUBLISHERS, INC., 250 Fifth Avenue, New York 1, N. Y.
For Great Britain and Northern Ireland:
Interscience Publishers Ltd., 2a Southampton Row, London, W.C.1

Printed in the United States of America

Preface

Within the last two decades the term 16-mm has become something more than the mere designation of a film width; it is now almost symbolic of all non-theatrical films. With little fanfare, the 16-mm film—which may be loosely called the film of fact—was catapulted into the leading position in the United States as a consumer of raw stock because of its use as a medium of teaching, training, and persuading in the same World War that proved the 35-mm film—the film of fancy—so valuable to the military and civilian populations in the maintenance of morale.

At the turn of the period about two decades ago, the entertainment motion picture industry was in the process of a technological revolution—the introduction of sound. Sound was unfamiliar and costly; its reception in the industry was mixed. Some firms gambled their all on it: its failure would wipe them out, its success would be their success. Others, seeing the mad rush of the public to their competitor's box office for pictures that talked, embraced it but said publicly that sound was a fad whose disappearance would be as rapid as its rise had been meteoric. Still others felt that sound would never acquire public acceptance; they installed it only when the signs became all too evident that the earnings future of the silent films stored on their shelves was very dim indeed. Some others just died. It was in such an environment that 16-mm as a vital force was born.

During the first decade, at the time when budgets were minute according to present day standards, and obstacles were seemingly insurmountable, the groundwork of the 16-mm film as it is known today was laid. It was during this period too that 16-mm sound recording equipment and 16-mm sound projectors began to be a factor to be reckoned with in the photographic market, due not so much to their accomplishments, but to their potentialities. Some viewed the growing baby with alarm, and shunned it as a dangerous potential competitor for the public's time and purse; a very few felt that it should be watched—much as one might watch the approach of an inevitable tornado that would leave a wide path of destruction in its wake. Others ignored it.

A decade later the groundwork of the 16-mm had been quietly completed. Hollywood was then deep in the throes of providing wide-range and high-fidelity sound; the question of the sound *vs.* the silent film had been answered by the public at the box office. The influence of the British documentary movement spearheaded by Grierson had already made itself felt in the United States. "The River" and "The Plow that Broke the Plains" of Pare Lorenz had established themselves as qualified American descendents of Robert Flaherty's "Nanook of the North," one of our earliest and best documentaries. The theory and practice of the training film had been lucidly and accurately set forth in a U. S. Army "Memorandum to G-3: Factors in Training Film Production and Use" dated February, 1936; this document had been prepared by Melvin E. Gillette within the Army. Gillette, like his Army associates, Hoorn, Jervey, and Stodter, had been trained in the mechanics of film production through the auspices of the Academy of Motion Picture Arts and Sciences; their study in Hollywood had been the culmination of the efforts of Prosser, Fox, Lewis, and others to make such training possible. Like all documents that live beyond the short life span of their authors, this one is timeless; it defines the place of the training film and of other films in relation to the national military establishment, and describes in straightforward language the principles that guide their production and use.

During the same period, the U. S. Navy laid the groundwork for the sound slide film; the work of Byron McCandless of the Bureau of Navigation will not be forgotten in Navy records. The names of Reifsnider and Fraser made their appearance a short while later in the Navy roster in the development of sound films for Navy recruiting. The U. S. Air Corps had also been active in training films. Hagemeyer, a civilian at Wright Field, will be remembered for his continued devotion and accomplishments over the same two decades. In 1931, a short series of films on pilot training had been turned out experimentally at Wright Field with the cooperation of RCA Photophone Inc.; these films were later sent to England to the R. A. F. The Department of Agriculture, through its Extension Service Office of Motion Pictures, had acquired sound equipment in 1930, and soon produced simple, effective, and low-cost factual sound films under the expert guidance of Raymond Evans, its Chief, and his associate, Chester Lindstrom. The films are considered models by which agricultural films are made everywhere today. Meanwhile, the amateur ranks, already large, swelled noticeably because of the

ready availability of Kodachrome and of cheaper and better cameras and projectors, and because of the availability of sound projectors and sound films for the home. Many amateurs became professionals in the 16-mm field; many professionals became amateurs.

Despite its age of over 40 years, the technical literature of the motion picture is surprisingly sparse and spotty. It is found almost entirely in short papers published in the journal of a single society: the Society of Motion Picture Engineers. A scientifically trained person with no prior knowledge of the industry would find these papers as many small curiously shaped pieces of a large jig-saw puzzle for which there is no over-all guide by which the pieces may be put together, or from which it would be possible to determine whether all the essential pieces are present. This book is the author's attempt to provide the first such technical guide. It has drawn liberally upon the *Journal of the Society of Motion Picture Engineers* for its material and its illustrations; the author wishes to express his sincere thanks to the Society and its officers and to the many authors of its papers for permission to use them. It is the author's considered opinion that an integrated and rationalized explanation of the processes of the 16-mm film would hardly be practicable without them.

It is hoped that the entire book will prove helpful to the newcomer to films. To the specialist in film technology its value may lie primarily in fields outside his immediate specialty. Its major usefulness, however, will be to that large segment of intelligent inquiring people making and using films, who believe that 16-mm has a tremendous impact upon national—and international—life, and yet find that some of its technological nuances seem to be a hazy puzzling mystery, rather than a rational and logical engineering and businesslike process.

Maxfield, a venerable of the sound film, once described the sound motion picture as ". . . the application of engineering equipment to an art . . ." Since the primary emphasis of the past has been upon the art and not upon the science, it is not a surprise to find that the nomenclature and terms used as its language are primarily non-scientific. There are many coined terms; a number of accepted definitions have several shades of meaning included in the American Standards Association nomenclature. Still other specialized terms are not industry-wide, and are used only in special places in special instances; many of these are unknown to the industry at large. It took almost 50 years before the first American Standard Nomenclature for motion pictures came into

existence; this listing, which is reproduced *in toto* in Appendix A, includes terms that have acquired wide acceptance, but does not include the specialized terms previously described. Even this excellent nomenclature can be improved; should the reader have specific suggestions, they will be sincerely welcomed by ASA and by the Society of Motion Picture Engineers, the sponsors of ASA motion picture standardization activities. Letters should be addressed to the secretaries of the respective organizations. It is respectfully urged by the author that universal use of this nomenclature be encouraged.

In view of its rapid growth, it was thought desirable to discuss television in a short separate chapter, and include numerous references. Right now, television and motion pictures are closely interlinked, as over 25% of the average 48 hours per week station operating time comes from film; in addition, a large volume of 16-mm film originates as live television shows that are photographed from the face of a television station monitor tube during a transmitted performance. Although television is being embraced by all concerned, there are many obvious indications of mixed feelings about it. So far there have been no Horatio Alger financial success stories to encourage the plunges of those faced with the decision. Radio broadcasters have to some extent viewed it as an expensive prestige-making offshoot of the sound broadcasting industry whose increased budgets will be borne by national advertisers about as they are in sound broadcasting. Some motion picture interests have viewed it as a potential supplement to theater programs; a small few view it as that inevitable destructive tornado. Few, however, are ignoring it. Dynamic television, like 16-mm motion pictures, cannot be successfully ignored. At the present stage there is only one safe prediction; the American public has many new and wondrous things in store—if the public wants them.

Acknowledgments

The author gratefully acknowledges the courtesy of the following companies, associations, and individuals in granting permission to publish illustrations:

Academy of Motion Picture Arts and Sciences (Fig. 34), *Altec-Lansing Corp.* (Fig. 114A), *American Standards Association* (Figs, 8, 9, 10, 11, 13, 19, 76, 78A), *The Ampro Corp.* (Figs. 108, 111), *D. Appleton-Century Co.* (Figs. 1, 1A, 1B), *Bell and Howell Co.* (Figs. 23, 24, 85, 88, 88A, 94, 103, 109, 112, 112A), *Oscar F. Carlson Co.* (Figs. 93, 102, 102A), *Cinema Arts-Crafts* (Fig. 101), *Eastman Kodak Co.* (Figs. 22, 84),*Electronic Development Associates and Ralph Batcher* (Figs. 38, 39), *Fonda Division, Solar Aircraft Corp.* (Figs. 92, 92A), *The Houston Company* (Fig. 91),

Jensen Radio Manufacturing Co. (Figs. 27, 28, 28A, 105A, 115), *Journal of the Society of Motion Picture Engineers* (Figs. 7, 12, 30, 31, 32, 50, 53, 54, 59, 60, 61, 65, 66, 68, 69, 70, 74, 75, 89, 90, 98, 107, 117–123), *J. A. Maurer, Inc.* (Figs. 7A, 7B, 25, 52, 58, 61A, 63, 63A, 63B, 71B, 71C, 80, 97, 99), *Mitchell Camera Corp.* (Fig. 26), *Moviola Manufacturing Co.* (Fig. 86), *National Association of Broadcasters* (Fig. 33), *National Bureau of Standards* (Figs. 116, 116A, 116B, 116C, 116D), *Neumade Products Corp.* (Figs. 77, 78, 79, 81, 82, 83, 87), *Photographic Instruments, Inc.* (Figs. 95, 96, 104), *RCA–Victor Division, RCA* (Figs. 44, 44A, 44B, 46, 46A, 46B, 48, 48A, 48B, 49B, 49C, 49D, 51, 64, 67, 71A, 100, 113), *Shure Brothers, Inc.* (Figs. 49, 49A), *E. I. Sponable* (Fig. 57), *U. S. Navy* (Fig. 110), *D. Van Nostrand Co.* (Figs. 34, 35, 36, 37, 40, 41, 42, 55), *Western Electric Co.* (Figs. 43, 43A, 43B, 45, 45A, 47, 47A, 47B, 55A, 62, 71, 114), *Weston Electrical Instruments Corp.* (Figs. 2, 3, 72, 72A, 73).

Thanks are also due to the *Society of Motion Picture Engineers* for permission to reprint in modified form material that appears in Chapters V, VI, IX, XI, XIV, and XV. Much of this material was previously published in its *Journal* by the author in the form of Society papers.

Although it is impossible to list all who have contributed professionally to the data in this book, special mention must be made of my fellow-engineer of many years, Dr. E. W. Kellogg. His influence as a catalyst in improving the quality and quantity of the work of all those with whom he comes in contact can be matched only by his own outstanding achievements in the field of sound recording. Special mention must also go to my old friend from Columbia student days, Hugh Knowles of Jensen. For years we have discussed 16-mm and what can be done to improve it. He is to be congratulated particularly for the excellent series of Jensen Technical Monographs that make loudspeakers and their performance comprehensible to engineers at large.

Mention must also be made of my friend and associate during the War, Lloyd T. Goldsmith of Warner Brothers, who in his continuous survey of the Hollywood scene is so keenly aware of the unusual things that are quietly being done there on the day-to-day job by the unsung scientific heroes of the picture production and equipment manufacturing industry.

The author is indebted to Harry Smith, Jr., former Secretary of the Society of Motion Picture Engineers for providing the spark that started this book. He also wishes to express his deep appreciation to Interscience Publishers, Inc., and especially to Mr. Allen Kent of their staff for understanding counsel and aid in producing this book.

Acknowledgment must also go to my good friend H. E. White of Eastman Kodak and to William Deacy, Jr., of the Society of Motion Picture Engineers in that necessary and taxing chore of going over the galley proof, and to my sister Marie for checking the page proof.

William H. Offenhauser, Jr.

New Canaan, Connecticut
September, 1949

CONTENTS

CHAPTER I

16-Mm Film and Its Relation to Other Sizes

Early History

About 50 years ago when Edison was getting his "peep-hole" Kinetoscope ready for the Chicago World's Fair of 1893, he chose 35-millimeters as the width for the film that he was going to use. The Kinetoscope, showing photographs in motion, was to be seen at the World's Fair for a nickel—and the nickel show which involved forty feet of film lasted all of 30 seconds. It is interesting to note that the 35-mm film used had substantially the same dimensions as the 35-mm film of today; it had the customary rectangular-shaped sprocket holes, and there were, on each side of the film, four per frame. 35-mm film is today well standardized; and 35-mm film made anywhere, when exposed in any camera made anywhere, and developed and printed in any equipment made anywhere, will project in any projector made anywhere in the world if the international standards that are in effect are observed.

International standardization of motion picture films and equipment, although informal at the very beginning, arose from a very natural desire of people to demand the widest potential use for any motion picture that might be made. Pioneers in various countries of the world used different film dimensions, but it was soon discovered by the showmen who bought the variegated machines that the different sizes were not interchangeable. Since Edison had produced most of the films, it was only natural for showmen to demand that their machines be capable of projecting Edison pictures. Thus, even prior to 1900 there was a strong demand for the standardization of film sizes that made itself strongly felt in the countries where the motion picture saw early and rapid growth—the United States, France, and England.

Quigley and Talbot reported that among those who bought Kinetoscopes were two Greek visitors from London, George Georgiades and George Trajedis; these men recognized the potentialities of the magic shadows. One was a green grocer, the other a toy maker; they saw an opportunity to make a fortune in England as showmen. The two Greeks acquired Edison machines in New York, brought them to London, and

sought out Robert Paul to duplicate the machine for them. Paul assumed that Edison had patented his machine in England and refused, pointing out that both he and they would expose themselves to patent litigation and heavy damages. The Greeks were dismayed, and departed, taking their Kinetoscope with them.

Paul then looked into the patent situation more thoroughly and found that Edison had not filed British patents upon his invention. Accordingly he was free to set to work and to build machines—and he did so for the two Greek entrepreneurs and others. Since only Edison films were widely available, Paul's Kinetoscopes were made for the Edison 35-mm film. When Edison's representatives Maguire and Baucus became aware of this, however, they took steps to cut off the supply of Edison films to Paul's machines. In the meantime, Paul who had recognized the limitations of the "peep-hole" viewing arrangement, set about building a projector which he called the Animatograph; this was Paul's design that resulted from a suggestion of Birt Acres, who at the time was in the employ of a firm manufacturing dry plates and bromide papers. In the early months of 1895 the Animatograph was built and first tested; this machine was probably the first to use a picture gate as we now know it and an intermittent movement. Since Paul's customers for the Kinetoscope had stretched from England to New Zealand, Paul was now forced to arrange for a supply of film to keep the machines running that he had sold. With his source of films cut off, Paul was forced to build a camera and to produce the films himself. It was at this point that Edison's agents decided to withdraw from England because of the ingenuity and persistence of Robert Paul.

Lumiere, a French firm manufacturing photographic apparatus and dry plates, was seemingly attracted to motion pictures by the Edison Kinetoscope as was Paul. Upon seeing the Edison machine in 1894 in Paris they recognized the drawbacks of (*1*) too many frames per second (the number was about 48), and (*2*) no opportunity for audience viewing. Lumiere set about building a camera, and a projector (called a cinematograph). Lumiere film was 35-mm wide and had just one round hole on either side of the frame; the holes were spaced 20 mm apart. The Lumiere machines and film represented excellent mechanical design, and in the earlier versions utilized a film strip 17 meters long rather than the Edison length of 40 ft. Progress was made very rapidly; in the autumn of 1896 a Lumiere projector introduced in the United States by a Mr. Hurd, agent for the Lumieres, projected a picture 22 by 16 ft.

As a result of this demonstration, Mr. Hollaman, manager of Eden Musee, signed a contract for its installation as a permanent feature. The motion picture industry owes much to the daring showmanship of Mr. Hollaman, since he was an outstanding pioneer in recognizing the possibilities of new motion picture equipment and films and in putting them into almost immediate commercial use.

Unfortunately for the Lumieres, Kinetoscopes had been sold more generally than had at first been supposed—many of these by Paul. It seems that both Paul and the Lumieres were mutually unaware of each other's activities, and the Lumieres were soon faced with a demand from their customers to alter their apparatus to accommodate the Edison film. When this was done, the first practical international (although informal) standardization of motion pictures was accomplished prior to 1900.

After 1900* the motion picture grew very rapidly all over the world. It would seem that the strong public demand could not be long restricted to the very narrow channels that even farsighted and enterprising promoters and entrepreneurs had charted for it.

To some extent history has repeated itself with 16-mm. Although it started as an amateur medium, it far outgrew its early swaddling clothes when it came into a real popularity with its extensive use as training and similar films devoted to military purposes.

Film Size

As the technology of the motion picture advanced from its enthusiastic yet humble beginnings, it was only natural to expect manufacturers of films and equipment to attempt to reduce costs to the point where films would be practicable for amateur and personal movies—enlarging the scope of motion pictures tremendously. One of the early steps† taken to satisfy that desire was the manufacture of smaller film,

* Early motion picture history is shrouded in a haze that is a combination of fact and fancy—with the latter predominating in the more popular works. Thanks are due to Mr. Terry Ramsaye of New Canaan, Connecticut, for his most generous suggestions in the location of reliable sources, and to Mr. E. F. Kerns of the Museum of Modern Art, 11 West 53rd Street, New York City, for his aid in locating the references cited at the end of this chapter. All references cited are to be found in the library of the Museum. An excellent source of accurate history is "Testimony of Witnesses for the Petitioners, in the District Court of the United States: The United States of America, petitioners, *vs.* Motion Picture Patents Company *et al.*, defendants.

† A much earlier small film that acquired popularity but has since disappeared is 28mm, sponsored by Willard B. Cook, an early pioneer. Home movie projectors were made by Pathescope (Cook) and Victor Animatograph; reduction printers by Pathescope; raw film was made by Eastman.

arbitrarily selected at 16 millimeters. It was not until about 1923, however, that the big step in making films really suitable for the amateur was made when the Eastman Kodak Company introduced reversal film on the 16-mm market. Prior to that time, all motion pictures—whether 35-mm or 16-mm—required *two* strips of raw film to produce the single strip used in the projector. When developed, the exposed original film provided a negative image that was dark in the bright portions of the scene and light in the dark portions. In order to obtain a positive image suitable for projection a copy had to be made on a second strip of film, with the bright portions of the scene being light and the dark portions dark. The process is quite similar to that used for film from simple still cameras.

Reversal Film. Obviously, if the original film could be developed directly into a positive image suitable for projection, the amount of raw film required would be cut in half, and the printing and the second developing operations eliminated. Reversal film processing accomplishes just this, and is today used almost exclusively for black-and-white original film of 16 millimeters and all lesser widths. This type of film is still unknown as original film in the 35-millimeter width; all such original film is negative—just as it was some fifty years ago when motion pictures were born.

Common Film Sizes

As time passed, attempts were made to broaden the market by reducing the cost of amateur motion pictures still further. In the United States, 8-mm film provided the answer; it was first introduced by Eastman Kodak in about 1934. 17.5-mm, made by splitting 35-mm in two, found a few specialized uses; original sound recording for Hollywood films was one example.

In France, 9.5-mm film had been introduced somewhat earlier, being used quite widely for educational as well as amateur purposes, and proving a strong competitor of 16-mm in popularity. Later, 9.5-mm equipment and films were imported into England, but have become of lesser importance since the fall of France in the early part of World War II. Since 9.5-mm did not make headway in the United States, it is unlikely that it will become a major factor now that World War II is over. Only 35-mm, 16-mm, and 8-mm need be given serious consideration for the future, since any other possible film width subsequently proposed for standardization will need a very strong case for adoption before it can be seriously considered.

Wide Film. Films larger than 35-mm were run in theaters for a limited period about 1930; among the better known were the 62-mm (RKO Spoor-Berggren), 65-mm (Paramount-DeBrie), and 70-mm* (Fox-Grandeur). None of these widths was standardized, and since 1933 none has been used commercially to any extent. It is interesting to note that these larger sizes had larger aspect ratios, since a wider picture in comparison with picture height was considered desirable.

Sound

When sound was introduced commercially into films in 1928 and 1929, it regenerated the motion picture industry and caused very rapid expansion and technical growth. At that time, sound recording equipment was used almost exclusively for 35-mm film, in view of unsuccessful earlier attempts at commercial recording directly on 16-mm film. Within a few years, 16-mm sound prints were being made commercially by optical reduction from 35-mm negatives (a picture negative for the picture original, and a sound negative for the sound original), and the availability of commercial entertainment pictures in the 16-mm film width enhanced its popularity. One of the earliest 16-mm sound projectors was designed by R. P. May of RCA in 1930. It was compact, light, and gave surprisingly good performance in comparison with the 35-mm portable sound projectors marketed at the time. Almost a decade passed before the performance of this machine was surpassed.

With the availability of such films and projectors in the 16-mm size, amateur and other nontheatrical film users began to think in terms of sound films rather than silent films, and a potential demand was created for 16-mm sound recording equipment.†

During the period from 1932 to 1936, 16-mm sound-recording equipment was marketed, but the quantity was small, and its usefulness handicapped by poor quality of the projected pictures and sound in that they did not compare favorably with the quality of pictures seen at local theaters.

During this same period, the edge had worn off the novelty of sound in the 35-mm entertainment motion picture theater, and serious efforts were made to improve the technical quality of the picture as well as of the sound. It was then that "wide range" and "high fidelity" became by-

* The dimensions of 70-mm film have been standardized for still camera purposes.

† Important among the nontheatrical users were educators. The advantages of films in education had been formally recognized as early as 1914 in an address to the National Education Association at St. Paul and in 1915 at a University of Minnesota Summer Session where scholastic credit was granted principals of consolidated rural schools who qualified as projector operators.

words for sound, and improvement was seen in all phases of recording and reproduction. By the end of 1936 there was a fair degree of consistency in the technical quality of entertainment films shown in 35-mm movie houses.

From 1936 onward represented a period of further improvement in 35-mm films and of both improvement and rapid growth in 16-mm films. When new developments in films or apparatus occurred in 35-mm film technique, it was not long before the new developments were adapted (where suitable) in 16-mm films—each size exerting strong technical influences upon the other.

Color

The presence of Kodachrome for motion pictures in the 16-mm film width and its equally notable absence in the 35-mm film width provided still further impetus to an already interested and active industrial and educational motion picture market. Almost immediately, this market began to demand color duplicates—*with sound.* Kodachrome made it possible to "shoot" in color and make a small number of copies at very low cost (when compared with available 35-mm methods, such as Technicolor). No special camera was needed, no special camera crew, and no long contract negotiations were required to obtain a desired color film. It was necessary merely to use Kodachrome in a good 16-mm camera to obtain the picture, with sound being recorded in much the usual manner. With this ready availability of both color and sound, the technological millenium of color and sound in educational films as envisioned by Edison had become a reality within but 50 years of the birth of the motion picture itself.

Military Uses of Film

World War I saw the use of motion pictures to some degree by every large nation of the world. The amount of 35-mm film used for record purposes ran into millions of feet. For training, the United States Army had prepared 52 reels of a series called "Training of the Soldier" and about 13 reels called "Elements of the Automobile." The Germans had their films too; it was remarked by one German general that in modern warfare the nation with the most complete photographic intelligence would be the likely victor. Even at that early time films were made for propaganda purposes (Germany and Russia) as well as for training. When World War II arrived, the motion picture, in principle, had been accepted as a training tool, although the amount of material

available was quite limited. The United States Army, Navy, and Air Forces had chosen 16-mm as the width best suited to their needs. Since there was a large quantity of 35-mm production equipment available such as cameras, sound recorders, editing equipment, etc., and a relatively large pool of personnel trained to handle this equipment, it was logical to assign to 35-mm the major part of the production burden. The 16-mm projection prints were obtained from the 35-mm films by optical reduction from special picture and sound duplicates copied from the edited negatives.

The volume of 16-mm prints made for training and similar purposes in World War II was measured in millions of feet per day. Such wide use resulted in even greater and more insistent demands for better technical quality in the projected films. In order to meet these demands, much technological improvement was needed in every stage of the process. As each improvement was made, it was crystallized into an American War Standard wherever possible. Standardization is being continued as a normal peace-time activity, and its accumulated effects cannot help but be felt throughout the world in the form of more and better films for more people—and at a lower cost.

Present Status

Today, 35-mm prints are used almost exclusively in the entertainment motion picture theater. 16-mm prints are now used almost exclusively by the Armed Forces of the United States in the training of military personnel. 16-mm prints are already widely used for educational and industrial purposes. 8-mm is now reserved almost exclusively for amateur and personal purposes.

So far, the optical reduction* of 35-mm to 16-mm has accounted for the largest percentage of prints released in the 16-mm size.

In a small number of newsreel theaters, 16-mm sound projectors have been installed beside 35-mm projectors to project 16-mm film upon the same theater screen. Andre DeBrie has made a 16-mm attachment for a 35-mm theater arc projector which projects a Kodachrome image on a 40 ft. screen with brightness and detail roughly equal to that from the best 35-mm color print. With very good control of film quality, the projected 16-mm films compare very favorably with 35-mm prints that may be used for comparison.

* As will be described in a later chapter, the picture for 16-mm prints is now obtained from dupes from the original negative; the sound is re-recorded on a 16-mm sound negative and contact-printed for the release print.

Another overlap of interest in recent years is the "blowing up" of 8-mm to 16-mm, and of 16-mm to 35-mm films. Much of the combat war material shown in the entertainment theaters was originally taken on 16-mm film. Typical examples have been the many air combat scenes photographed with the GSAP (Gun Sight Aiming Point) camera, a 16-mm camera designed to take pictures of an enemy target when the machine guns or other guns of the combat plane were fired. Where originals were well exposed, well handled, and well processed, the results were satisfactory.

Up to the present, no serious commercial attempts have been made to record sound on 8-mm film. Without sound, it is unlikely that any large portion of the present interest in 16-mm film will be transferred to the 8-mm size. It is unlikely that 8-mm sound can be handled commercially with sufficient quality and uniformity that it need be given serious thought in the immediate future for educational and similar uses. For the next several years we can expect much attention to be concentrated on the 16-mm size for still further improvement in quality and broadening of scope and use.

It would be impracticable to set forth in a volume of this kind anything more than a few of the rudiments of 16-mm technology. At the end of each chapter is a short bibliography. Most of the data on the motion picture is recorded in current technical journals and similar publications and is not available in texts. References to such publications when pertinent are at the end of each chapter. Only a limited amount of data will be given concerning equipment and methods used in producing 16-mm prints from original films or other widths, such as 35-mm. These data are already available from other sources, such as the *Journal of the Society of Motion Picture Engineers* and the *Journal of the British Kinematograph Society.*

The comparative table (Table I) indicates the relative sizes, weights, and like characteristics of 35-mm, 16-mm, and 8-mm.

16-mm was originally intended to be simple and low in cost. It is not reasonable to expect 16-mm apparatus and methods merely to be scaled-down, 35-mm apparatus and methods. Simplicity, reliability, operating convenience, small size, and economy are still essential requirements—without these, 16-mm film fails its real purpose.

For educational and similar low-cost films, the need for simplicity dictates the elimination of all time-consuming practices (whether in production, processing, or utilization) that do not deliver the maximum

result per man-hour expended. All apparatus and processes should be utterly reliable; time and effort expended should assure a specific result at a specific cost of such time and effort. It is only in this manner that costs can be kept to an absolute minimum and the widest distribution obtained for films of maximum utility.

TABLE I
Characteristics of Various Sizes of Films

Characteristic	Size		
	35-mm	16-mm	8-mm
Length, ft.	1000	400	200
Linear speed,[a] ft. per min.	90	36	18
Running time, min.	11.1	11.1	11.1
Relative length	2.5	1.0	0.5
Relative weight and volume	5.5	1.0	0.25
Relative area for picture	4.6	1.0	0.25
Relative area for sound	3.15	1.0	

[a] A speed of 24 frames per second is assumed.

Selected References

All references listed below may be consulted at the Museum of Modern Art Film Library, New York City. For further historical data, the reader should refer to the following publications of the Society of Motion Picture Engineers (earlier publications were called *Transactions;* currently called *Journal*): *Index* for July 1916 to June 1930 under *Historical* and *Home Motion Picture Equipment,* page 131; *Index* for January 1930 to December 1935 under *Historical* (pages 31–32), *Home Motion Picture Equipment* (page 32), *Sixteen-Millimeter Equipment* (pages 57–58), and *Progress* (pages 50–51); *Index* for 1936 to 1945 under *Historical* (pages 96–98), *16-Mm* (pages 125–126), *SMPE Activities, Committees, Progress Reports* (page 129).

Quigley, Martin, Jr., *Magic Shadows.* Georgetown Univ. Press, Washington, D. C., 1948.

Talbot, F. A., *Moving Pictures.* Lippincott, Philadelphia, 1912.

Talbot, F. A., *Practical Cinematography.* Lippincott, Philadelphia, 1913.

Ramsaye, Terry, *A Million and One Nights.* Simon & Schuster, New York, 1926.

The Film Index—A Bibliography. Museum of Modern Art and Wilson, New York, 1941.

Day, Wilfred, *Historical Collection Catalog.*

Dickson, W., and Dickson, Antonia D., *The Life and Inventions of Edison.* Crowell, New York, 1894. One page 304 of this text is a sketch showing the photographing of a sound film. The sound-recording phonograph is shown on the left, and the motion picture camera on the right.

Bayley, R. Child, *Modern Magic Lanterns.* Gill, London, 1895.

Mazo, E., *La Projection au XXe Siècle.* Paris, 1903.

The Modern Bioscope Operator. Ganes Ltd., London, 1910.

Richardson, F. H., *Motion Picture Handbook.* New York, 1910.

Dyer and Martin, *Edison, His Life and Inventions,* Vol. II, Harper, New York, 1910.

Niewenglowski, G. H., *Traité Pratique des Projections Limineuses Spéciales.* Paris, 1912.

Manuel Pratique les Projections Animées. Edition du Courrier Cinématographique, Paris, 1913.

Horstman and Tousley, *Motion Picture Operator.* Drake, Chicago, 1914.

Sloane, T. O'Connor, *Motion Picture Projection,* New York, 1922.

Sinclair, Upton, *Upton Sinclair Presents William Fox.* Los Angeles, 1933.

Victor, Alexander, ''The History and Origin of 16-Mm.'' Am. *Cinematographer, 26,* No. 11, p. 376, 384, 396, November 1945.

Dickson, R. W., ''The Development of 16-Mm Sub-Standard Film,'' *British Film Yearbook, 1947–1948,* 193–197, 197–200.

Krows, A., *Motion Pictures—Not for Theaters, a Series.* Educational Screen, Chicago, cir. 1939.

The Central Information Bureau for Educational Films Ltd., *A National Encyclopedia of Educational Films and 16-Mm Apparatus Available in Great Britain.* London, 1935, 1937.

CHAPTER II

Making a 16-Mm Picture

Subject Matter

Before procedure and equipment for making a 16-mm picture can be considered, there must be subject matter to be portrayed. This subject matter is usually prepared in the form of script that not only describes in detail that which is to be portrayed, but also breaks down the material into the specific settings, actors, properties ("props"), action, and sound required for each scene. The script is customarily prepared so that the scenes will have the sequence planned for the edited picture.

Script. It is beyond the scope of this book to discuss the script, the actors, the settings, and other elements related to the subject matter to be portrayed. It must be stated at this point, however, that the script should be written with such care and in such detail that the activities of all persons connected with the production of the picture are clearly and completely specified or implied. In the absence of such clear and detailed information, the picture when finished cannot help but reveal any inherent uncertainty of the script. The script is the specification for the picture. A good picture can be made from a good script; a good picture cannot be made from a poor script.

Taking the Picture

Let us assume that a simple sound film is to be made; this requires both camera equipment and sound equipment. If the film is to portray the operation of a certain piece of machinery, for example, it is necessary to have the machinery available, lighting equipment to illuminate it, camera equipment to photograph it, and sound equipment to record whatever accompanying sound is required.

Lighting. The amount and kind of lighting equipment required depends primarily upon the size of the area to be photographed—the greater the area the larger the equipment. Many 16-mm subjects are fairly small—no larger than the shoulders of an individual.* For such

* Souther, H. T., "The Theory and Practice of Lighting for the Camera," *JSMPE*, 46, 254. (Apr. 1946).

small areas, three reflectors equipped with Photoflood lamps are usually sufficient. Generally speaking, the average subject requires front lighting, cross lighting, and high lighting. A #4 Photoflood is often used in the reflector for front lighting and a #2 Photoflood in each of the other reflectors. Should the subject be darker than average (a black velvet cloth, for example) more light is required; if the subject is lighter than average (a white sheet), less light is necessary. The amount of light available is measured with an exposure meter. From the calculator on the exposure meter is determined the *f* stop or lens aperture setting required on the camera for the film used.

If required by the script, the picture may be photographed under natural daylight; in such a case the Photofloods and their reflectors are not required. Photographing in daylight often presents production problems not encountered within the studio; clouds cannot be controlled nor can rain be stopped with the same ease involved in turning on the switch energizing the Photoflood bulbs for artificial lighting.

The Camera. The motion picture camera photographs the scene. It has a lens through which light is focused on the film to record the image. Two settings must be made on the camera lens; one, for the distance of the camera from the subject, called the focus setting; the other, for the amount of light admitted to expose the film, called the aperture, *f* stop, or opening setting.

Lenses are made in different focal lengths; for the same image size on the film, a shorter focal length means a shorter camera-to subject distance, while a longer focal length means a longer camera-to-subject distance. Lenses are commonly available in focal lengths of approximately 15-mm (3/5 in.), 1-in., 2-in., 3-in., and 4-in. sizes. As the camera-to-subject distance is often determined by some characteristic of the space in which the picture is taken (*e.g.*, a wall may be near the machine to be photographed) lenses of different focal lengths are ordinarily required in the making of a given picture.

The perspective of the photographed picture is altered when lenses of different focal lengths are used on the camera. For a viewer located approximately in the center of an audience watching a 16-mm film, perspective is approximately correct when a camera lens of 1-in. focal length has been used. For this reason the 1-in. lens should be used whenever it gives a satisfactory picture; lenses of other focal lengths should be used only if the image with a 1-in. lens is either too large or too small.

The Camera Motor. The camera is usually driven by a synchronous alternating-current motor that drives the camera with little or no significant speed variation.

Speed variation of the camera would result in an inaccurately exposed film where the image density or blackness would not be uniform from one frame of the film to another.

The Camera Tripod. To avoid a "jiggling" picture, the camera must be mounted on a camera tripod. This is merely a very steady three-legged stand on which the camera rests. Since the magnification of the picture increases with an increase in the focal length of the camera objective lens used, the tripod should be increasingly steadier when lenses of longer focal length are used if the same amount of "picture jiggle" is to be tolerated. When lenses of 4 inches and longer focal length are used, the tripod should be very rigid and steady. A gyro-head tripod makes smooth lateral movement (called "panning") and smooth tilting possible; this type of tripod is very widely used for newsreel and similar pictures. For studio-made pictures a simpler friction-head type is usually used because the gyro head is too noisy indoors when sound is being recorded. The noise is produced by the gyroscope gear train during panning and tilting.

Film for the Picture. The film to be used in the camera is made in rolls of standard lengths of 50, 100, 200, and 400 ft. The film is placed in a light-tight compartment known as a magazine. When the camera is running, the film leaves the feed spool of the magazine, goes through the camera, and returns to the magazine on the take-up spool. A single magazine usually has the feed and take-up compartments within a single housing.

The film for the 16-mm motion-picture camera is customarily either black-and-white reversal or color reversal. After a reversal film is exposed in the camera, it is usually developed in a laboratory owned or provided by the film manufacturer. The sale price of the reversal film customarily includes the cost of developing. When developed, a reversal film has the highlights and shadows in proper relationship for the scene photographed, and not interchanged as they are in the negative of film used for a still camera.

Recording the Sound

Simultaneity. Sound may be recorded either at the same time that the picture is taken or at some other time. With the exception of Holly-

wood entertainment pictures and the like, most 16-mm pictures have the sound track made at some different time.

Single *vs.* Double System. When sound is recorded at the same time that the picture is taken, it may be recorded on the same strip of film that holds the picture (single system recording), or synchronously on a separate strip of film (double system recording). Because picture film is not usually suitable for sound recording purposes, almost all 16-mm sound films are made with double system recording.

Sound-Production Crew. Sound recording requires a separate group of operators (a sound crew), consisting in the simplest case of one additional man. It is impracticable to have one man attend to both camera and sound recorder, since he could not concentrate properly upon either. When time is an important production factor, the camera crew and the sound crew will each consist of at least two men.

The director is the manager of the entire production crew. It is his responsibility to turn out the product (the picture) according to the specification (the script).

Sound-Recording Equipment

The Microphone. The sound-recording equipment starts with a microphone that picks up the sound and converts it into minute electrical currents. A microphone may be a nondirectional condenser or dynamic microphone and pick up sound substantially uniformly from all directions; these types are usually the lightest and smallest. A microphone may be a bidirectional ribbon microphone and pick up sound from front and rear but not from the sides; this type is quite large and heavy but has excellent fidelity. A microphone may be a unidirectional cardioid-type microphone and may pick up sound from a wide angle in front but not from the sides or rear; this type is intermediate in size and weight. The unidirectional microphone is rapidly displacing other types because it can discriminate to some extent against noises that originate from directions other than that of the sound to be recorded.

Directional microphones have three great advantages: (*1*) they can reduce to some extent the noise made by a running camera, (*2*) they can reduce the effect of reverberation (echo and blurring) caused by the reflection of the sound from walls, floor, ceiling, and other hard surfaces, and (*3*) they pick up sound at somewhat greater distances.

The Microphone Boom. The microphone must be so immersed within the sound field that it will pick up sound of the proper quality and

volume. This is usually accomplished by hanging the microphone at the end of a fishpole-like arrangement known as the microphone boom. The weight of the microphone determines the weight and size of the boom. The lightest microphones weigh a pound or less and the heaviest about 8 pounds. A boom for a heavy microphone, being long, is really quite a massive affair; the larger booms usually have cranks for twisting the microphone on a swivel, cranks for turning the boom, and cranks for shifting the microphone along the boom. Recording sound is definitely more than a one-man job when a large boom is required to follow the voices of actors moving around a set.

The Amplifier. A cable from the microphone runs to the amplifier where the minute currents from the microphone are amplified and otherwise altered to actuate the sound-recording machine. A pair of headphones or a monitor loudspeaker is provided so that the recordist may hear the sound that he is recording; there is also a visual meter called a volume indicator. Some form of power supply is needed to energize the recording amplifier; this may be a set of batteries, or, more likely, an arrangement to adapt current from the power line to the amplifier.

The Sound-Recording Machine. Two sets of wires run from the sound-recording machine. One, connected to the power line, supplies power to the motor that runs the film through the machine; the second, connected to the amplifiers, supplies the currents that are translated into photographic images by the light modulator of the sound-recording machine. Sound may also be recorded on magnetic tape.

The Magazine. The sound-recording machine, like the camera, has a two-compartment magazine in a single housing. When the sound recorder is running, the film leaves the feed spool of the magazine, goes through the sound-recording machine, and winds onto the takeup spool in the magazine. The film used is customarily in standard lengths of 400 ft.; most magazines are designed for a roll of this size.

The Film. The film (raw stock) for the sound-recording machine is quite different from that for the camera. In the case of a variable area recorder a special film is used that has been designed and manufactured especially for sound recording*. (Eastman Kodak 5372 is a film of this

* Prior to 1946, most 16-mm sound recording machines sold on the open market were of Maurer manufacture; these were variable-area machines. The few 16-mm machines made by RCA, although convertible for variable-density recording, have been used almost entirely for variable-area recording. Western Electric Co., the major manufacturer of variable-density machines, had only a half-dozen or so in use. Although most modern machines are now designed to provide either variable area or variable density at will, most 16-mm machines are still recording variable-area track.

type.) Fortunately, these films are much cheaper than picture film and are admirably suited to their intended purposes. The price of sound film does not include the cost of developing, but there are several independent commercial film laboratories that will develop the sound track. However, since something more than "just developing" is usually wanted, it is necessary to be specific in telling the laboratory just what is wanted and how they are to go about doing it.

The Exposure Lamp. To expose the film, light is needed; this is supplied by an incandescent lamp mounted in the recording machine. The exposure is adjusted by a rheostat that changes the lamp brightness. An ammeter is customarily used in the lamp circuit to measure the current; the brightness of the lamp is measured in terms of the ammeter reading.

The Light Modulator. Interposed between the exposure lamp and the film is the light modulator. This alters the amount of light reaching the film in strict accordance with the sound currents fed to it by the amplifier.

Developing and Printing for Editing

Picture Developing and Picture Work Print

The reversal or color picture film is sent to the film manufacturer's laboratory for developing. When ready, a frame-by-frame copy of the original picture is made (called a work print). For identification purposes, the original picture is often edge-numbered with sequential footage numbers; these edge numbers are copied on the picture work print along with the picture image.

Sound Track Developing and Sound Track Work Print

The sound track is sent to a commercial laboratory for developing When ready, a copy called the sound work print is made. Again, for identification purposes, the original sound track is often edge-numbered with sequential footage numbers; these numbers are copied on the sound work print along with the sound image.

Rough Assembly of Work Print

Temporarily, the original picture film and the original sound track are set aside for safe-keeping. The picture work print is cut into sections, rearranged into the sequence called for in the script, and spliced

together. The result is a rough-assembly edited picture work print. Simultaneously, the sound work print is cut into sections, rearranged into the same sequence, and spliced together. The result is a rough-assembly edited sound track work print. The master guide throughout all editing is the script.

Rough-Cut Work Print. At this point in the editing, each scene is trimmed to approximately its desired length and content. Although picture is on one strip of film and sound on another, both may be run in synchronism on a special editing machine to judge the effect of the combination. The result of this editing is a rough-cut; there are now on hand a rough-cut picture work print and a rough-cut sound track work print.

Final-Cut Work Print. We are now ready for the finishing touches of the final cut. The synchronism of the picture and the sound track is checked and re-checked, and the film is viewed in the projection room for approval for release. Last-minute alterations are made where needed, and the film is approved.

Cutting the Originals

In the editing process just completed, many pieces of film remaining in the final picture have been handled again and again. During this handling, the film becomes scratched and marred as well as dirty. The work prints were made to avoid all handling of the original until the *exact* arrangement of the final film was determined.

The original picture with the original sound track and the edited picture and sound work prints are turned over to a "negative cutter." In this work, order rather than chaos is the rule when the edited film is edge-numbered and otherwise identified accurately. A negative cutter is trained to handle the film only with gloves. He cuts apart the original films, removes the portions to be deleted, and splices the remaining pieces to match the work prints exactly. He then splices on suitable leaders and their synchronization and printing marks, and the films are ready for release printing. The negative cutter is the fine jeweler of film handlers; his workmanship, neatness, and efficiency are the pride and joy of the whole film craft. When he makes a splice, no trace of smear of film cement appears to mar any part of any frame that he has handled; film that he has assembled is just as clean, bright, and new as it was when it first came from the developing machine.

Release Printing

First and Subsequent Trial Composite Prints. The originals, now complete, are sent to the laboratory for the making of release prints. The laboratory makes a first trial composite of picture and sound as a sample. The owner or producer studies it and reports to the laboratory the printing corrections desired. The laboratory then makes a second trial composite, incorporating the printing corrections specified. This time things should be the way they are wanted, and the laboratory is given the order for the production run if a small number of prints (say, 25 or less) is required.

Duplicates and Masters. If a large number of prints is required or if the owner plans to preserve the original so that more copies may be made at a later time, the laboratory is not given an order for release prints at this time; it is instructed to make up a duplicate of the picture and to use a re-recording (an electrically-made copy) of the sound track provided by the owner. These intermediate copies are used to make the release prints. From the intermediate copies the laboratory is instructed to make a first trial composite release print. Once again the owner or producer studies the print just made and reports his wishes to the laboratory; in this case he compares the trial composite release print just made from the duplicates and masters with the trial composite print that he approved before the intermediate copies were made.

Quality of Release Prints. The quality of the picture and sound of a release print made from duplicates and masters will be poorer than that of the trial composite print made directly from the originals because of the losses added in the additional steps. If the difference is small, the duplicating work has been good; if the difference is large, the duplicating work has been poor. A good set of originals deserves good release prints, since the audience that the owner wishes to reach will never see the originals. The laboratory can turn out good release prints if the owner demands them, and will pay just a little more to get them.

The foregoing is a simplified description of the procedure and equipment used to bring a 16-mm sound film into being. Each portion may be modified or expanded to suit the needs of a particular situation. How well the job has been done shows up at the end of the process: the projection of the release print before an audience.

CHAPTER III

16-Mm Film and Its Characteristics

''Motion picture film* is a thin flexible ribbon of transparent material having perforations along one or both edges and bearing a sensitized layer or other coating capable of producing photographic images.'' This definition confines motion picture film to a film in which the image-bearing portion is on the surface; the definition bars the use of the term in connection with Ozaphane and similar films that utilize a light-sensitive diazo dyestuff distributed uniformly throughout the film.

Although this chapter will deal almost entirely with silver-emulsion-type films, the diazo dyestuff film type should be mentioned, since it holds future promise for commercial use in certain conditions of application. Diazo dyestuffs may be manufactured inexpensively; many show resolving power in excess of the best that has been obtained with silver-emulsion films. With the dyestuff distributed uniformly throughout the base, the films are not as seriously affected by surface scratching and abrasions as are silver-emulsion films. Diazo films are photographically slow; they require great exposure to provide the photographic image. Since the image is developed in ammonia gas, there is no need for alternate wetting and drying of the film; better dimensional stability can be obtained with the same base material. Copying with a single exposure results in a photographic image of the same highlight-shadow aspect as the material being copied; a positive copy image is produced from a positive image in single development. Most diazo films have high contrast. Although early diazo films gave poor reproduction of highlights and shadows, newer diazo films are being devised that show promise of overcoming many of the early reproduction handicaps.

Silver-Emulsion Films

Although silver-emulsion films have been in use for more than 50 years, very little has been published on many important phases of film

* According to definition 1.1 of American Standard Nomenclature for Motion Picture Film Used in Studios and Processing Laboratories—ASA Z22.56–1947, the term ''film'' may be applied to unexposed film, to exposed but unprocessed film, and to exposed and processed film.

manufacture and use. Emulsion-making is one such phase; manufacturers have usually considered this to belong to the practice rather than the theory of photography. With the technical voids in the literature that this attitude produced, it is difficult for a new student to obtain a balanced over-all view that can be expanded as needed for specific specialized applications. As in any other field of technology, motion pictures require an understanding of the raw material (the film) in order to understand properly the finished product.

There are two basic parts of a light-sensitive film: (*1*) the support (called the base); and (*2*) the photosensitive material (called the emulsion). There are two kinds of base material in general use in motion pictures, nitrate base (essentially cellulose nitrate), and safety base (essentially cellulose "high-acetyl"). Nitrate film base is never used for 16-mm film since it is barred from interstate commerce in the United States. Nitrate film is combustible and a fire hazard; safety base is slow-burning and is no more combustible than an equal volume of paper. 16-mm safety base is 0.005 in. thick (in manufacture the thickness is quite uniform).

The emulsion is usually made in the form of two or more layers of silver halides suspended in gelatin; it is coated on one side of the base. The total thickness of the emulsion is about 0.001 in.; emulsion thickness is very uniform. The emulsion is bonded to the base by a solvent-cement that usually contains cellulose nitrate; the weight of nitrate, however, is but a fraction of one per cent of the total weight of the film.

Film Manufacture

The manufacture of 16-mm film consists of the following main steps:

(*1*) Base manufacture.
(*2*) Emulsion manufacture.
(*3*) Coating the base with the emulsion.
(*4*) Slitting and perforating.

Base Manufacture

A liquid mixture that is essentially cotton and acetic and other acids together with solvents is fed continuously into a narrow hopper several feet long. The long narrow orifice through which the liquid emerges by gravity provides mixture flow at a very uniform rate to the periphery of a slowly rotating drum (usually made of stainless steel) that is several feet in diameter and several feet wide. As the drum rotates, the solvents evaporate and a film of base material forms on the drum. After

rotation through a portion of a revolution, the film is peeled off in a continuous sheet. It is usually necessary to trim the edges of the sheet as they are not of uniform thickness. The sheet is then rolled up into a suitable length for coating. A typical length is 2000 ft.; a typical width might be 6 ft. After rolling, the base material is stored until needed for coating.

The composition of base mixture is not fixed; it differs in wide degree from one manufacturer to another for presumably equivalent products. It may differ in appreciable degree from one group of products of a particular manufacturer to another group of products of the same manufacturer. It differs also to a lesser yet important degree from one batch of manufactured material to another made by the same manufacturer. The exact mixture used for a particular batch of base material is determined by the performance that the film manufacturer desires and expects to obtain. Users should expect to find measurable and important differences in physical characteristics (such as shrinkage, flexibility, toughness, etc.) for example, between Eastman fine-grain positive, #5302, and DuPont fine-grain positive, #605A. We should not be surprised to find important differences in characteristics between two batches of a particular material; such differences are inherent in any manufacturing process and product.

Users should look for good performance in a test sample of a product and also make certain that the batch-to-batch uniformity is good, so that good performance can be maintained in the finished product as a routine operating matter.

*Emulsion Manufacture**

Since gelatin holds the silver halides in suspension, the preparation of the gelatin is very important in the process. Gelatin has several chemical functions as well as physical ones; some of these follow.

(*1*) It acts as a protective colloid to maintain the dispersion of the silver halides and to protect them from reduction by a developer without exposure.

(*2*) In solution it enables a stable suspension of silver halide particles to be formed.

(*3*) In the jelly state it supports mechanically the microscopic particles of silver halide and silver and permits soluble materials to act upon them.

(*4*) It affects the sensitivity of the silver halide.

(*5*) It combines with, and thus removes, the halogen liberated by the action of light.

The physical functions that are just as important are as follows.

* Mees, C. E. K., *The Theory of the Photographic Process.* Macmillan, New York, 1944.

(*a*) It acts to adhere to and cooperates mechanically with the base.

(*b*) It shows minimum mechanical distortion when swelled (as during developing) and shrunk (as during drying and subsequent use). Not only must it suffer minimum distortion itself during such swelling and shrinking, but it must also cause the halide crystals and their corresponding silver nuclei to suffer minimum distortion and shift in orientation.

Gelatin is usually made from selected clippings of calf hide and ears, and cheek pieces and pates. For photographic purposes, all pieces must be free of bacterial infection. Two common processes are used in refining gelatin; they are known as the lime-acid process and the soda process. Both processes require soaking of the pieces for an extended period (several months); as the character of the gelatin has a marked effect upon the sensitometric characteristics of a finished emulsion, the particular process used to refine the gelatin depends upon the effects desired in the emulsion to be manufactured.

Emulsion Preparation Stages. There are three important stages in the preparation of an emulsion:

(*a*) Emulsification and the initial ripening;
(*b*) Removal of excess soluble salts;
(*c*) After-ripening and the sensitizing.

(*a*) *Emulsification and Initial Ripening.* Emulsions are usually prepared by mixing solutions of 10% or more of soluble halides with silver nitrate solution. (Silver bromide is one of the common halides in most emulsions whether of the negative or of the positive type; most negative types also contain some silver iodide.) To prepare the emulsion, a small amount of relatively inactive gelatin is swelled in cold water and then heated to form a melted gelatin solution; this gelatin is only a small percentage of the total required for the finished emulsion.

The alkali halides are then added; an excess of potassium bromide is always used. Silver nitrate solution is then added while the gelatin solution is continuously stirred; it is necessary that there be an excess of bromide even locally where the nitrate enters the gelatin solution. The halide precipitates formed are always microcrystalline; the crystals when first formed are so fine that when viewed by transmitted light, the solution appears deep red. When more nitrate is added, some of the precipitate forms around the fine crystals already present—increasing their size—while the remainder of the precipitate forms small new crystals.

Upon completion of the addition of the nitrate solution, there is still an excess of bromide; under this condition the emulsion is ripened by

heating. In the ripening process, the larger crystals become still larger and the smaller crystals smaller; this is called initial ripening, digestion, or Ostwald ripening of an emulsion. During heating, the gelatin partially decomposes causing minute silver sulfide specks to form on the halide crystals. Although these silver sulfide specks (called sensitivity specks) play a very important part in the formation of the latent image, the exact nature of the very complex physicochemistry involved is just beginning to be understood.

In general, coarse-grained, higher speed emulsions result from the slow addition of the nitrate to the potassium bromide solution in addition to ripening for a relatively long time at a relatively high temperature. Finer grained, lower speed emulsions (such as process emulsions) result from more rapid addition of the nitrate together with ripening at lower temperatures. It is interesting to note that at this early stage of manufacture, the grain distribution of the finished emulsion is established and continues substantially unchanged throughout the remainder of the manufacturing process, and to a degree, during subsequent developing after exposure. After the initial ripening, gelatin of the chemically active type is added to bring the gelatin content of the heated mixture to approximately 10%. This step is very important since the subsequent sensitometric effects to be obtained depend upon the properties of the gelatins so added. After this gelatin is thoroughly dissolved, the emulsion is set in a cool place. In a few hours it sets to a stiff, jelly-like mass. At this point, the emulsion has low contrast and low sensitivity.

(*b*) *Removal of Excess Soluble Salts.* The emulsion at this point still contains the soluble potassium nitrate that was formed with the silver halide and an excess of potassium bromide. It is washed to remove these soluble salts; if this were not done, they would crystallize out during drying when the emulsion was being coated on the base. The presence of these salts would also interfere with proper second ripening. Water is ordinarily used; washing is controlled by the rate of flow and by the temperature of the wash water used. In order to make washing easier, some emulsions are shredded into "noodles" by forcing the gelatinous mass through a wire screen or perforated die or plate. During the washing process, the halide crystals, being insoluble in water, are held mechanically in position by the gel structure and remain unaffected.

(*c*) *After-Ripening and Sensitizing.* After washing is completed, the emulsion is drained and then melted for the after-ripening; the remainder of the gelatin required for the finished emulsion is added at

this point. The second ripening results in a very considerable increase in sensitivity without a serious increase in grain size; this is especially true of negative-type emulsions. As in the case of the first ripening, the increase in sensitivity is due in appreciable measure to the sulfides produced as a result of the partial decomposition of the gelatin. The temperature and time of heating depend upon the gelatin used and the effect desired.

Over-ripening results in a serious increase in fog; under-ripening results in a slow continuation of the ripening process during subsequent storage, which continues even after the emulsion is coated on the base. Proper ripening is indicated by maximum sensitivity and minimum fog; over-ripening results in an unstable emulsion that fogs rapidly in storage, under-ripening results in an unstable emulsion whose sensitivity increases during storage. As has been mentioned previously, after-ripening is extremely important for high-speed negative types of emulsions; it is of far less importance with positive emulsions—especially those of the process type.

At the conclusion of the second ripening stage, the emulsion is chilled and stored until needed. Such an emulsion may serve as the basis for several products depending upon the nature of the sensitizing dyes and other ingredients that are added just prior to coating. Up to this point, variations in the individual steps of the process determine the essential character of the emulsion as to speed, contrast, graininess, and latitude.

Coating the Base with the Emulsion

Just prior to coating, the emulsion is treated for color sensitivity, keeping quality, fog, and—to a degree—speed, by the addition of very small quantities of other substances, including sensitizers. The materials used and the manner of application and treatment are closely guarded secrets of the film manufacturers; very little has been published on the subject. The natural color sensitivity of silver halide emulsions centers in the region 350 to 450 millimicrons; positive-type emulsions such as fine-grain printing positive and raw film for sound negatives for variable-area recording are of this type that we may call blue sensitive.

The addition of small quantities of absorbing dyes (as small as 1 part in 100,000 parts of water or dilute alcohol solution equivalent) will cause an emulsion to show color sensitivity for other colors in addition to blue. Even though the dye used must actually stain the silver halide crystals in order to be effective, yet, of dyes that stain, only a comparatively few

are sensitizers. Some sensitizers are extremely unstable to light, others quite stable. The exact nature of the sensitizing action is still obscure, although numerous theories have been evolved to explain many of its aspects.

Positive-type emulsions intended for duplicating purposes usually have a relatively large quantity of yellow dye mixed into the emulsion; the effect of this dye is more physical than chemical since it tends to prevent or reduce intercrystal reflection and diffusion and the reflection of light to the emulsion from the base after the light has passed through the emulsion during exposure. The use of the yellow dye materially increases the resolving power of an emulsion at the expense of sensitivity; more incident light is needed to produce the same density. Yellow-dyed and similar emulsions have been used satisfactorily for sound negatives for 16-mm where high resolving power is needed for good sound records.

A finished liquid negative emulsion contains about 6% gelatin (dry weight) and 4% silver halides. This mixture is coated upon one side of the base after an extremely thin under coat or "subbing" coat has been applied to the base to cause the emulsion to adhere to the base. The emulsion is warm when applied and is chilled as it passes over a chilled roll after coating on the base. The emulsion is then dried. A typical coating in liquid form might be 1/100 in. in depth; this dries to something like one-tenth its application depth. Modern emulsion coating techniques usually include multiple coatings for even black-and-white films; multiple coatings are absolutely essential in integral tripack color films such as Kodachrome and AnscoColor. The total emulsion thickness for all layers of color film is but little more than that of the simplest black-and-white films.

Slitting and Perforating

Film is usually slit and perforated just prior to shipment. It is slit into appropriate widths (in this case 16-mm in width) and perforated. Both the slitting and perforating operations must be performed very carefully; film manufacturers are meticulous about maintaining the mechanical tolerances of the finished film. The film is cut to typical lengths of 50, 100, 200, 400, 800, 1000, 1200, 1600, and 2000 ft. Upon cutting, the film is mounted upon cores or spools (as required) and packed and prepared for shipment.

50, 100, 200, and 400-ft. lengths are in common use in 16-mm cameras. 400-ft lengths are usually used in sound recording machines, although some amateur-type and special equipment may use 100 and 200-ft. lengths.

Television cameras and recording machines, especially those for recording from video monitor tubes, often use film in 1200 foot rolls. 400, 800, 1000, and 1200 ft. are common lengths in use in film laboratories where copies of films are made; 1600 and 2000 ft. are lengths that are used infreqently even in film laboratories.

Although extreme care is used in manufacture and in supervision and inspection during manufacture, it must be realized that the quality of perforating and slitting varies from manufacturer to manufacturer and, for a particular manufacturer, varies from time to time. The tools and dies used are subject to wear; the quality delivered depends to a great degree not only on how well the tools were designed and made but also on how well they are maintained. To make it possible to check mechanical variations, manufacturers of film maintain accurate manufacturing logs and also mark each can of film shipped with sufficient identifying code numbers to aid in tracking down any possible deviation from standard deviation in manufacture.

General Comment on Emulsions

The control of emulsion quality exercised by film manufacturers is of a high order; it is quite rare that defective or inferior emulsions of regularly manufactured products such as Kodachrome, reversal film, duplicating negative, duplicating positive, and release fine-grain positive raw film get into circulation. This does *not* mean that all lots of a particular type of emulsion are alike; emulsions vary from lot to lot to an even greater extent than does film base. The sensitometric characteristics of a particular lot depends not only upon its characteristics at the time of manufacture and test by the manufacturer, but also upon the changes in characteristics as a result of storage during the interval between manufacture and use. Temperature is a very important storage condition; generally speaking, a constant temperature of approximately 50° F. is most suitable for most films. As a result of improved manufacturing processes, the storage characteristics of films have been improved greatly in the last few years. Not only has there been considerable improvement in the base, but also in the length of time that a film may be stored before use (as measured by a predetermined permissable change in sensitometric characteristics, such as fog, etc.) has been increased to the point at which manufacturers can safely guarantee their products for a period of at least one year even on high-speed, negative-type films.

In buying film it is well to ascertain that the film purchased is fresh, a particularly important consideration in the case of high-speed emulsions and in color film. Good commercial practice dictates that film shall not be used when it is old. In the case of low-speed materials such as yellow-dyed duplicating positive, this is not so important if the film has been stored properly.

In general, it is necessary to make test exposures and to gather other sensitometric data to ascertain the operating characteristics of film materials that are to be used for commercial purposes. If this procedure is followed regularly, old material is readily detected. Should it be used subsequently, its limitations are known beforehand and its unusual characteristics taken into account. If the probable quality is at all doubtful, special care should be taken in the preparation and interpretation of such test data.

Although 16-mm raw film is a complex product, it is an excellent product under good control as it is now manufactured. The control exercised in its use, however, is rarely of an order that compares with that of manufacturing control. Both exposure and processing are in need of close watching; it is indeed rare that the results obtained in release prints even begin to approach the capabilities of the raw film. Roll-to-roll variations in the characteristics of raw film of the same emulsion lot are quite small; special pains are taken by film manufacturers in storing film materials and manufactured raw film to *assure* that the variation from roll to roll will be a minimum. Such storage involves keeping temperature and humidity constant; the variations permitted are minute when compared to the variations found in places where the film is subsequently handled.

When storage conditions in the interval between manufacture and use are uniform (as is the case in film manufacturers' plants) it is reasonable to expect but a small roll-to-roll variation in the same emulsion lot even when the storage period has been as long as several months; the conditions, however, must also have been optimum. Obviously, the variation increases as the storage period becomes longer.

It is definitely unreasonable to expect two rolls of film of the same emulsion lot to show similar characteristics if one has been stored for a long period near a heated radiator or steam pipe and the other under more normal conditions. In any case, the temperature of a storage place for raw film should not exceed 70° F. The importance of reasonable care in the storage of film can hardly be overemphasized.

Physical Characteristics

Shrinkage

The continued evaporation of solvents and of moisture tends to shrink processed and raw film with storage time. This evaporation is accelerated by heat and low humidity; the heat from a projection lamp is a typical source of accelerated drying. Usually, film will reabsorb moisture if it is rehumidified, but cannot reabsorb the solvents that have evaporated, leaving a brittle product. When film absorbs moisture, it swells and becomes enlarged; as it dries, it shrinks. Shrinkage is usually expressed as the percentage difference between the measured length of a 100-sprocket hole interval and its nominal length of 30.00 in. (The nominal distance between two adjacent sprocket holes is 0.300 in.)

With such films as sound-recording positive (Eastman Kodak 5372) an ultimate shrinkage of 0.5% is the maximum to be expected. Somewhat less than this shrinkage should be found if the film is stored in an air-conditioned laboratory where such negatives are printed. Raw film (when it is removed from the can) should not exceed 0.20% ; more common values lie between 0.05 and 0.15%. If 16-mm raw film used for sound recording should exceed 0.20%, it should be looked upon with suspicion. With some release fine-grain positive films (DuPont 605A) a shrinkage of 0.9% is the maximum to be expected. Somewhat less than this (approximately 0.6%) should be the maximum in one-year-old films in film libraries and similar services.

Within the next few years—as soon as manufacturing conditions permit—all 16-mm base material will be of low-shrinkage types. This is but one example of the upward trend of raw film quality that has been going on without fanfare for almost a decade.

The shrinkage of reversal film and of color film will also lie in the same range. Most investigations of shrinkage have shown that the emulsion of a film as manufactured is quite elastic; the measured shrinkage appears to be controlled almost entirely by the characteristics of the base. For a number of years it was tacitly assumed that the physical characteristics of safety base would be inherently inferior to those of nitrate base, especially with regard to toughness, flexibility, and shrinkage. Very important improvements have been made within the last few years; continued improvement seems highly probable because of the tremendous increase in demand for safety base for 16-mm film. The improvement in performance has now reached the point where the American film manufacturers

plan to discontinue the manufacture of nitrate base film for use in 35-mm, and to substitute the new safety bases. This step will do much to remove the fire hazard always present where nitrate base films are used.

Emulsion Hardness

Emulsions are hardened during manufacture by a process similar to the process for tanning leather; this treatment reduces the tendency of the emulsion to soften and stick at high temperatures and humidities. Release print fine-grain films are especially hardened during manufacture to provide maximum service in use. Hardening agents may be introduced at quite a number of points in the film manufacture and use cycle; hardening is often introduced at more than one point. Some of the points where hardeners may be introduced are:

(*1*) Prior to coating of the emulsion upon the base.
(*2*) Before development or during development.
(*3*) Between development and fixation.
(*4*) In the fixing bath.
(*5*) After fixation.

Hardening is especially important if film is to be processed at elevated temperatures (above 70° F.) or if the film is run in a camera, printer, sound recorder, projector, or other machine at high temperatures and humidities.

Sensitometric Characteristics

To evaluate the properties of photographic materials requires numerical measurement; the analysis by means of suitable measurements is known as sensitometry. For convenience in analysis, the relation between the blackness of the developed silver image and the illumination used to provide the exposure is measured by means of the relationship of the common logarithm of the opacity of the image to the common logarithm of the exposure. These functions are defined as follows:

$$\text{Density} = \log_{10}\text{Opacity} = \log_{10}\frac{1}{\text{Transmittance}}$$

where:

$$\text{Transmittance} = \frac{\text{Transmitted flux}}{\text{Incident flux}}$$

Because of the variations in the amount of light diffusion that occur in practice, measurement of the transmitted flux and of the incident flux is not a simple matter. The incident flux may be diffuse, semi-diffuse,

or it may be a parallel beam incident upon the film at an angle. Some of the incident flux is absorbed, some reflected—the remainder transmitted. In the case of a film, the transmitted flux must be "collected" in some manner as it is scattered by the film emulsion which is microcrystalline in structure. If numerical measurements are to have meaning, measurement variables must be reduced to a minimum; this is accomplished by the "American Standard Method of Determining Transmission Density of Motion Picture Films" ASA Z22.27–1947. American Standard diffuse density designates densities determined under the practical geometric conditions provided by any one of three standard means and methods. These conditions approach the ideal conditions for totally diffuse density given in Section 3.1.1 of the Standard as closely as practical equipment and methods permit. As the subject is extensive and involved, reference should be made directly to the American Standard for details.

Practical densitometers other than the specified standard types must be calibrated. As most commercial densitometers are not standard types, calibration consists in the measurement of density samples with a standard densitometer and comparison of the results with the practical densitometer under test. If the conditions under which the practical densitometer are used are consistent, measurements are ordinarily reliable. Practical densitometers are designed to measure density values directly on a density scale of the instrument; they are also designed for convenience in operation. The type of practical densitometer used depends upon the accuracy with which the results are to be determined. For ordinary measurements in the range of 0.1–3.0, the Eastman 2A densitometer, a direct-reading optical wedge type instrument manufactured by Eastman Kodak, is satisfactory and low in price (approximately $100.00). For the measurement of fog (the density of unexposed but developed and fixed-out film) where the values are less than 0.1, a more accurate densitometer is required, particularly in measurements of fine-grain positive film developed in good developers. Common fog values for fine-grain positive are in the order of 0.01. For measurements in this range, the Martens polarizing-head densitometer (obtainable through Ansco) and the Western Electric RA-1100 photoelectric densitometer (obtainable from the ERP Division of Western Electric) are suitable and reliable instruments. The Eastman 2A densitometer is quite rugged; the Martens and the Western Electric instruments require care in handling similar to that required by a good compound microscope.

Exposure is measured in terms of the meter-candle-second (that exposure produced by a standard candle for a period of one second at a distance of one meter). Standardized exposures for routine test purposes are usually obtained from test sensitometers such as the Eastman IIb. Photometrically calibrated lamps are provided with this instrument for standardizing purposes. Other standardized exposures may be provided in operating equipment such as cameras, sound recorders, printers, etc.; these are often working standards that are referred to the IIb exposure as a reference. The Eastman IIb, although a time-scale device that is obsolete and no longer manufactured, is used; no other instrument has such wide use and acceptance despite the real need for other sensitometers.

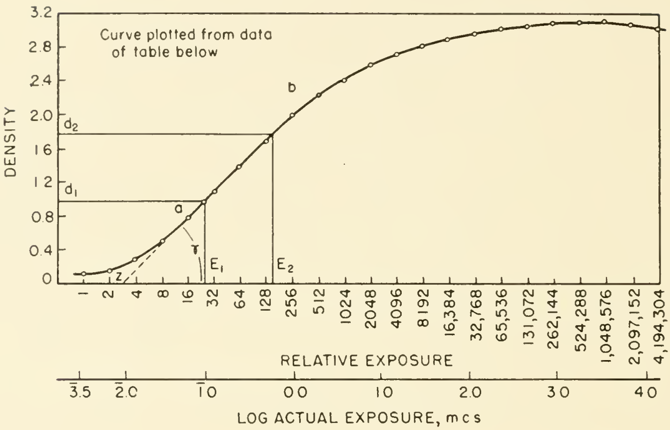
When film characteristics are graphically plotted, the result is an H&D curve—so called because it was first described by Hurter and Driffeld. An H&D curve (Fig. 1) is similar to a single sweep of a hysteresis loop (B-H magnetization curve) or of a stress-strain curve. It shows the relationship between density plotted as the ordinate, and log exposure, as the abscissa. The slope or gradient of the curve—called the gamma—indicates the relationship between the change in density and the change in log exposure. This may be more simply defined as:

$$\text{Gamma} = \frac{\triangle\ \text{Density}}{\triangle\ \log_{10}\ \text{Exposure}}$$

The value given for gamma is the value at the center of the straight-line portion of the H&D curve.

When used in connection with development, "gamma" refers only to development contrast. Development contrast is not related to subject contrast since it is dependent upon the character of the photosensitive material, upon an arbitrary series of exposures, and upon the development. As the numerical value of the gamma obtained depends upon the conditions under which it is measured, comparisons among similar materials may be made in terms of the gamma measured with a IIb sensitometer. In this case, the color temperature of the light source is 3000 K., the exposure is changed from one step to another by changing the exposure time and maintaining the light intensity constant. There are 21 exposure steps; the maximum exposure time is 4.16 second, the minimum exposure time is 0.00406 second, and the midstep exposure time is 0.130 second. Each step is related to the next adjacent in the ratio of $\sqrt{2}:1$. The gamma determined with this sensitometer is usually referred to as the IIb gamma.

Within a limited range, gamma can be varied by changing developing



Test Data for Fast Negative Film Developed 7 Minutes in a Tray at 65 F in a Negative Developer Bath

Step No.	Actual exposure, m.c.s.	Relative exposure	Log actual exposure, m.c.s.	Density	Step No.	Actual exposure, m.c.s.	Relative exposure	Log actual exposure, m.c.s.	Density
1	0.003802	1	3.580	0.12	13	15.56	4,096	1.192	2.71
2	0.007603	2	3.881	0.16	14	31.12	8,192	1.493	2.81
3	0.01521	4	2.182	0.29	15	62.23	16,384	1.794	2.88
4	0.03041	8	2.483	0.50	16	124.5	32,768	2.095	2.95
5	0.06081	16	2.784	0.78	17	248.9	65,536	2.396	3.00
6	0.1216	32	1.085	1.08	18	497.7	131,072	2.697	3.03
7	0.2432	64	1.386	1.38	19	995.4	262,144	2.998	3.06
8	0.4864	128	1.687	1.68	20	1991.	524,288	3.299	3.08
9	0.9728	256	1.988	1.99	21	3981.	1,048,516	3.600	3.08
10	1.945	512	0.289	2.24	22	7962.	2,097,152	3.901	3.05
11	3.890	1024	0.590	2.41	23	15920.	4,194,304	4.202	3.00
12	7.780	2048	0.891	2.58					

Fig. 1. Characteristic H & D curve for fast negative film shown in table above. This curve, named after Hurter and Driffeld, is obtained by plotting density as ordinate *vs.* multiples of exposure (logarithmic scale) as abscissa. (Exposure is measured in meter candle seconds.)

time used; a short developing time results in a lower gamma. Typical IIb gammas for some generally used 16-mm materials are in Table II.

Gamma may be reduced by:

(*1*) reducing developing time;

(*2*) using short-wavelength illumination for exposure (ultraviolet or blue-violet) instead of heterochromatic illumination;

(*3*) reducing the developer contrast (using a negative-type developer to replace a positive type);

(*4*) using yellow-dyed film or lower contrast raw film.

TABLE II

Development Gammas (IIb) of Widely Used 16-Mm Raw Films

Material	Manufacturer	Developing time, min.	Bath	IIb gamma
Release positive	DuPont 605A	4	Positive[a]	2.85
Duplicating negative	Eastman 5203	3	Negative[b]	0.45
Sound-recording negative	Eastman 5372	6	Positive[a]	
Duplicating positive	Eastman 5365	9	Negative[b].	1.40

[a] Positive bath refers to Eastman D-16 bath (with 1/3 less water) as a reference.
[b] Negative bath refers to Eastman D-76 bath as a reference.

Gamma may be increased by:

(*1*) increasing development time;

(*2*) using longer wavelength illumination for exposure (not suited to positive-type emulsions such as release positive or sound recording as these emulsions are color blind to red);

(*3*) increasing developer contrast by (*a*) using a positive-type developer to replace a negative type, (*b*) increasing developer agitation (developer agitation should not be reduced as a means of lowering gamma because of the greater development uniformity that occurs with higher agitation, (*c*) replacing partially exhausted developer with fresh developer (developer is best continuously circulated with frequent periodic makeup (additions) to maintain developer energy within the intended limits), (*d*) increasing developer bath concentration;

(*4*) using higher contrast raw film.

Generally speaking, it is good practice when first attempting to use a new material, to develop it at standard temperature and near the center

of its development time *vs.* density range. Should an increase or a decrease in gamma be indicated from the first tests, process readjustments can be readily made. (Such readjustments might be a change in developing time or a change in the developer bath concentration or composition.) The values given in the foregoing table of IIb gammas have been found satisfactory in one commercial laboratory for the materials specified when picture is step-contact printed throughout in providing 16-mm release prints from 16-mm reversal or Kodachrome originals through the means of a black-and-white, fine-grain intermediate duplicate negative.

It must be remembered that the brightness range of an average outdoor scene is quite beyond the maximum reproduction range of a 16-mm release print; the photographic process must compress this brightness range and reduce the mid-range brightness quite materially. In the various processing and duplicating steps between the original film and the release print, the curvature of the toe (the lower exposure portion of the H&D curve) and the curvature of the shoulder (the higher exposure portion of the H&D curve) should be checked carefully to produce the most pleasing tonal scale in the release print. While the differences in the shoulder characteristics of competitive black-and-white release print materials are quite small, there are considerable differences among the toe characteristics. Improvement in picture quality can often be made by careful choice of release-print raw film most suitable with regard to toe characteristic.

Grain, Grain Size, and Graininess

Silver halide crystals in an emulsion are always microcrystalline. A study of the grain characteristics of emulsions indicates that grain-size distribution follows quite closely the usual probability distribution in the case of fine-grain materials. Until the advent of the electron microscope, it was impossible to photograph small-size emulsion grains; in fine-grain film the emulsion grains are so small that the usual optical microscope will not resolve them. In the finest grained emulsion known, the Lippman emulsion, the average grain diameter is approximately 30 millimicrons; the smallest grains are of the order of 10 to 15 millimicrons, and the largest 45 to 50 millimicrons. The grain size distribution is very uniform and follows the normal probability distribution accurately. In fast negative emulsions, the average grain diameter is much larger—of the order of 2 microns. In coarser grained emulsions, grain-size dis-

tribution is usually decidedly "skewed"* due to the clumping of grains; in the Lippman-type emulsion, there is little or no skewing.

Routine comparison inspections of grain can be made with optical microscopes; a convenient arrangement is photographing at 2500 diameters and projecting with an enlargement of $\times 4$. Although the grain outlines are fuzzy because a magnification of 10,000 diameters is beyond the resolving power limit of the optical microscope, the technique is still useful, since grain areas can be measured and emulsions compared despite the fuzzy outlines of the images produced.

The limit of the usual optical microscope is of the order of 0.13 micron with light of 365 millimicrons wavelength (near ultraviolet). The limit of the electron microscope is of the order of 4 or 5 millimicrons. Grain size and physical characteristics of emulsions were the subjects of much conjecture until the electron microscope made the smaller grains clearly visible. After photographic film is exposed and developed, the developed grains are found to occupy approximately the same position as the undeveloped halide grains. Developed silver grains do not, as a rule, have the same shape as the undeveloped halide grains from which they are derived; they are particles composed of masses of twisted filaments of metallic silver. The similarity of grain position and size between the halide grain and the developed silver grain seems greatest for low-speed, fine-grain emulsions (such as the Lippman) where the halide grains are most uniform in size and in size distribution and do not clump.

Graininess in prints is influenced markedly by the graininess of the original. The best duplicating films are fine-grained and photographically slow compared with the best negative materials (relatively coarse grained and fast). Graininess is always aggravated by copying; the increase in graininess is least when the finest grained duplicating materials are used; and most when coarsest grained materials are used. Since the conditions under which an original is photographed are often subject to control, the photographer should make certain that his original has minimum practicable graininess.

Graininess of an original increases with:

(*1*) Degree of development—which may be measured as development gamma; a particular film will be more grainy when developed to a higher gamma than when developed to a lower gamma.

---

* *Skewed distribution* (statistics). The state or quality of a frequency distribution (of grain sizes) of being distorted by lack of symmetry, *e.g.*, being bunched together on one side of the average and of tailing out on the other side.

(2) An increase in processing temperature above normal—graininess increases very rapidly with even small increases in developer temperature.

Much research has been done by Eastman Kodak and DuPont in recent years to find new emulsions of physical and sensitometric characteristics suited to high-speed (developing time less than 1 minute) and high temperature (about 120° F.) processing. It is expected that the same general considerations will hold among new materials that may be evolved despite the fact that the new emulsions have to function under conditions of greatly accelerated chemical activity.

When a process has a negative–positive step as is the case in making black-and-white release prints from a release dupe negative printed from a reversal original, it is possible to reduce release print graininess materially without change of picture contrast by reducing the development gamma of the dupe negative and increasing the development gamma of the release print; the different and (not too well understood) graininess *vs.* gamma characteristics of negative and positive materials provide the opportunity. Although graininess in a negative over small ranges of gamma change increases somewhat linearly when negative gamma is increased, graininess in a positive quickly reaches a "plateau" value at a relatively low positive gamma and there is very little increase in graininess with increase in gamma beyond the point at which the plateau is reached. It is therefore possible to increase the positive gamma materially without sensible graininess increase, and to offset the gamma increase in the print by a corresponding reduction in dupe negative gamma to obtain a material reduction in graininess of the dupe negative. Surprising improvements in release print quality are obtainable in this manner. Incidentally, there is considerable variation in the graininess–gamma characteristics of different developer solutions; the appearance of developed silver grains as viewed under a microscope varies according to the developer used.

Graininess is a subjective effect; to a great extent it results from the nonuniformity of distribution* of the emulsion grains. Projected pic-

* Within the last decade, a very large part of the improvement in the graininess characteristics of negative and other films has been effected not so much by a reduction of the size of the average grain, but by improving the grain size distribution characteristics, making them approach more accurately a normal probability distribution of size rather than a skewed distribution as was common in earlier emulsions. Much undisclosed progress has already been made in the application of ultrasonics and like modern methods to effect the very real improvement that has already occurred, and still further progress can be expected in the future.

tures appear grainy long before individual grains or clumps of grains can be distinguished. Graininess is more noticeable with high-speed coarse-grained emulsions than with fine-grained emulsions. Visual graininess appears at a maximum for relatively large areas of uniform density at a density of about 0.4. Since either an increase or a decrease in density results in a different graininess value, comparisons between films mean little unless both the density and the area to be compared are the same. If the comparison is one of films alone, it is obvious that films to be compared should be developed under the same developing conditions and viewed or measured under the same conditions. Such conditions preferably should be typical of the conditions of use.

While there has been little investigation of graininess in connection with sound recording, it does not seem likely that substantially different considerations hold for sound than for picture reproduction. Fine-grain materials usually produce a reduction in distortion and noise when used for sound films. These reductions are quite large; in general, it is good practice to use the finest grained materials available for the intended purpose.

Resolving Power

The ability of an emulsion to record fine detail is called the resolving power of an emulsion. A test pattern is photographed or copied to determine the numerical value of the resolving power; this is a set of parallel lines in which the width of the lines is equal to the width of the spaces between them. The numerical value of the resolving power is usually expressed in lines per millimeter for the just-distinguishable lines.

As customarily used, the term is rather loose; film manufacturers usually mean the maximum number of lines per millimeter that can be distinguished visually with the particular film exposed and developed under conditions optimum for the emulsion, and measured under the optimum viewing conditions (adequate illumination and magnification) using "white" (heterochromatic) light of daylight or of mazda quality. It is apparent that the term as used by film manufacturers is not a direct measure of the resolving power obtained under actual conditions of use, as every operating condition encountered in practice is different from its corresponding test condition; resolving power measurements made in practice with a motion picture projector projecting the test images on a screen always fall quite short of manufacturers' ratings. Despite this, manufacturers' values are an indication of the comparative ability of various emulsions to record fine detail and are reasonably reliable for

comparing similar types of films, but less reliable for comparing different types. For ordinary purposes, resolving power ratings provide a reasonable index of over-all performance if it is recognized that small differences (of the order of 5 to 10% or less) are not likely to be significant.

In the practical measurement of resolving power, there are a number of factors which should be considered that affect the numerical values obtained:

(*1*) The line to space ratio of the test object.

(*2*) The test object contrast. (A relatively high contrast of constant value will introduce least error in measurement.)

(*3*) Level of illumination (not especially important).

(*4*) The chromatic characteristics of the light used for the exposure. (An increase in resolving power at the blue and at the red ends of the spectrum usually occurs.)

(*5*) Development conditions: (*a*) developer—some developers improve the resolving power of some emulsions; (*b*) development time—as development time is increased, resolving power reaches a maximum and then drops off somewhat; (*c*) developer concentration—an increase in concentration of a customary metol-hydroquinone developer produces an effect similar to an increase in development time with a lower concentration; and (*d*) developer temperature—a loss of resolving power can usually be expected as a result of temperature increase of a developer.

(*6*) Dyes in the emulsion. The use of yellow dye can double the resolving power of an emulsion. (There is a serious loss in sensitivity, however, and the development contrast is reduced appreciably. When yellow dye is incorporated in an emulsion, it is usually a water-soluble dye that is removed during developing.)

(*7*) Grain characteristics. With small grain size and a correspondingly large number of grains, much better resolution is obtained.

Tables III to IX, which will be found later in this chapter, list the resolving power ratings along with other data.

From a user's standpoint, the resolving power ratings currently provided by film manufacturers are little more than a qualitative guide, as the specific test conditions under which a published value is obtained are rarely if ever explicitly stated in published technical data. Almost invariably, the measurement tolerances of stated values are not stated explicitly; in the absence of such information, published data is of little quantitative value to a user in connection with a specific problem with which he may be faced. The user is forced to make tests under his specific conditions of use, and to forego any practical evaluation of his tests in terms of the percentage of the theoretical maximum realized by the manufacturer.

It would seem that the amount of film in commercial use is now sufficiently large and its application sufficiently varied to justify some serious

attention to the standardization of resolving power measurements from the user's standpoint. Manufacturers evaluate different materials in different ways; as the testing of film by a manufacturer may be considered part of the manufacturing process, it is of no interest *per se* to the user. But the application of the film in such a manner as to obtain the largest percentage of its quality potential at minimum cost is of unquestioned interest to users. The absence of "utilization efficiency" has for a long time given rise to inexcusable economic waste in the film industry. There are few large fabricating industries within the United States that know as little about their raw materials as the film utilization industry.

16-mm sound films are used for two primary purposes: the reproduction of picture and the reproduction of sound. Both are evaluated by an audience from the user's standpoint when a release print is projected. There should be available means of evaluating the performance of a film with respect to its reproduction capabilities before it reaches the final testing ground of projection before an audience. The methods should be standardized through the American Standards Association even though they may be empirical, and even though use may indicate a need for modifying them as more experience is gained in measurement.

As a beginning, there would seem to be need for two different evaluations—one for picture and one for sound. A single visual method might be agreed upon for picture evaluation; this might follow the general methods used by film manufacturers with such modifications as will make them practicable for use with a minimum of specialized apparatus, testing conditions, and personnel. For evaluating the sound film, a different test might be applicable; this would take into account the greater collimation of the illumination, and the linear response of the photoelectric cell, and might even take into account the movement of the film. (During projection of the picture, the picture image is ordinarily stationary in the projector aperture.) The sound evaluation might take the form of a sound optical system; a simple evaluation means is sorely needed for comparing the performance of black-and-white with other films such as color integral tri-packs.

In copying films it should be remembered that every photographic step has a significant copying loss. The cumulative effect of these losses is considerable; the loss in each step should be reduced to a minimum by the use of the raw film with the very best resolving power characteristics obtainable under the conditions of application. The importance of re-

ducing the loss at each step to a minimum can be appreciated if it is recognized that resolving power losses of 30% or more are quite common in a single copying step with good materials under good control.

Diffusion, Turbidity, Sharpness, Image Spread, and the Eberhard Effect

When the grain size of an emulsion is very small (such as in a Lippman* emulsion) there is relatively little effect during development of developed grains that had been exposed, upon adjacent grains that had received no exposure. As the grain size increases, the effect of exposed and developed grains upon adjacent unexposed grains tends to increase. The effects are of two types—physical, due to light-scattering effects among the crystals of the emulsion, and chemical, due to the retarding action upon development caused by the products of development. These terms do not include halation in their meaning, since halation is not an emulsion characteristic but is rather the spurious reflection at the back surface of the emulsion support.†

By reason of diffusion that results from reflection, refraction, diffraction, and light scattering at the halide grains, the image of a knife edge has a diffuse rather than a sharp boundary. Sharpness is defined as the rate of change of density with respect to distance into the shadow of a knife-edge image. It is usually determined by means of a microdensitometer trace showing the transparency variation across a knife-edge image on a film under test. As photoelectric cells respond linearly to incident light flux, sharpness is ordinarily evaluated at the midpoint between maximum and minimum transparency. If a slit with parallel knife edges is in contact with an emulsion, the developed image will usually

* Lippman made extremely fine-grained emulsions by mixing together quickly, and at as low a temperature as possible (about 35° C.), solutions of silver nitrate and potassium bromide, to each of which half the necessary gelatin had been added. These emulsions are transparent when first mixed, the precipitated particles being submicroscopic in size. If they are allowed to stand (at 35 to 40° C.), they become opalescent and, finally, opaque. (Lüppo-Cramer and Eder *Eder's Handbuch*, 3 Aufl., 1927, Band II, Teil 1: 7.)

† Halation is evidenced as a spurious image that degrades the quality of the intended image because of stray exposing light that has passed once through the emulsion and is reflected back to the emulsion by the clear base of a film and/or other partially reflecting support. Such spurious light rays are ordinarily absorbed by a light-absorbing dye located between the emulsion and the base, or by a dye incorporated in the base itself. Reflected or refracted light rays causing halation degrade the image very materially because of the many passages of such rays past boundaries between media of different indices of refraction.

be wider than the slit. An emulsion is said to have low turbidity when the image size approaches that of the test object. A Lippman emulsion has zero turbidity for all exposure levels. Other emulsions show an increase in turbidity with an increase in exposure above a specific exposure value for a specific material. Turbidity is usually defined as the amount of spreading per unit increase in $\log_{10}$ exposure.

Generally speaking, the numerical evaluation of turbidity is considered by film manufacturers to be in the province of the research laboratory of the film manufacturer and of no concern to the film user. This is presumed to be the case because of the difficulties encountered in evaluating the test results, which are usually in the form of a microdensitometer trace. Comparative tests are more feasible for film users; they are made by photographing a slit with an optical wedge placed against it to attenuate the light logarithmically from one end to the other. Photomicrographs are then made and compared visually.

If a number of small circular areas are exposed with a certain exposure and a number of large areas are likewise exposed with the same exposure, it will be found that in customary developers the density of the large areas is smaller than the density of the small areas. This effect, called the Eberhard effect, is attributed to the retarding action upon development caused by the products of development.

Another manifestation of the same effect is a somewhat higher density at the outer edge of a uniform exposure area; the density at the center will be a minimum. Developing machines are usually designed to sweep away the products of development rapidly, keeping the Eberhard effect to a minimum.

Types of Available Film

In 1924, when reversal film was first marketed, the number of available types of 16-mm films were few; they consisted merely of one reversal type, one negative type, and one positive type. The volume of 16-mm film manufactured has since grown to the point where it is significantly large compared with 35-mm raw stock production. The increase in quantity has been accompanied by an increase in the number of types available. These are:*

* Most terms used in this chapter are in accordance with "American Standard Nomenclature for Motion Picture Film Used in Studios and Processing Laboratories"—ASA Z22.56–1947. On the whole, the nomenclature used in films is likely to be confusing because there are many ambiguities. Alteration of standard definitions where made is for the purpose of reducing ambiguity.

Original Film Materials

(*1*) Reversal film (black-and-white) for original photographing.
(*2*) Color reversal for original photographing.
(*3*) Positive-type dyed film for variable-area sound originals.
(*4*) Negative film for special purposes (rarely used commercially).

Duplicating Film Materials

(*5*) Dupe negative—fine grain.
(*6*) Master (dupe) positive—fine grain.

Release Print Materials

(*7*) Black-and-white release positive—fine grain.
(*8*) Color-reversal print stock.
(*9*) Reversal (black-and-white) print stock.

Original Film Materials

(1) Black-and-White Reversal Film

''Reversal film is a film which after exposure is processed to produce a positive image on the same film rather than the customary negative image. If exposure is made by printing from a negative, a negative image is produced directly.''

Reversal films may be either panchromatic black-and-white or color, and either sound or silent, and they are usually 16-mm and narrower in width. As currently manufactured, most reversal films are of high contrast suited to projection.

As has already been mentioned, the film used in the 16-mm camera is customarily a reversal film. Like most other modern film for picture taking, black-and-white reversal film is usually made in two or more emulsion layers. The top layer usually has higher speed (and coarser grain) than the layer below it; this layer arrangement materially improves the exposure latitude. Figure 1A is a photomicrograph of the cross section of a modern two-layer film.

Reversal film is given reversal processing.* The film first enters a developer bath where the larger emulsion grains are developed, being most sensitive to light. The film next enters a bleach bath that bleaches out the larger film grains just developed, leaving the remainder of the film unaffected. The film is next given a second exposure or ''fogging'' over its entire surface, exposing the finer emulsion grains that were unaffected by either the original exposure and by the first developer. The film next enters a second developer bath in which the finer emulsion grains are developed and produce the blacks of the final image that appears on the film.

* Reversal processing is described more completely in Chapter XII.

As the blacks (shadows) and the whites (highlights) have been changed from their inverse relationship such as is found in a still camera negative, the film is known as reversal film and the development method as reversal processing.

Reversal films are manufactured in two general types, universal reversal, which may be developed as either a negative or as a reversal at will, and regular reversal, which may be developed only as a reversal Generally speaking, universal reversal films, being intended primarily

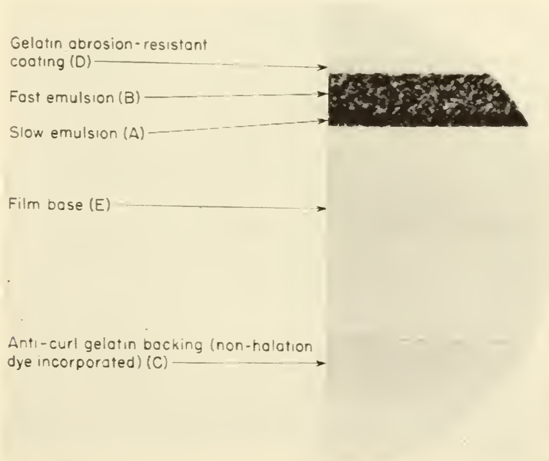


Fig. 1A. Photomicrograph of the cross section of a modern black-and-white film. This shows (A) the slow emulsion layer adjacent to the base, (B) the fast emulsion layer on top of the slow layer, (C) the anti-curl gelatin backing that contains a dye or a silver deposit to minimize halation, (D) the gelatin protective overcoating that prevents abrasion marks in the emulsion proper and resists abrasion because of its physical hardness, (E) the film base. Negative films and duplicating negative often have the anti-halation dye in the film base rather than in the gelatin backing. The film base is clear if the film is to be used for projection. Duplicating positive films often have a water-soluble yellow dye in the emulsion that is dissolved out of the emulsion when the film is developed.

for duplication and not for direct projection, utilize an anti-halation dyed base; regular reversal films, being intended primarily for direct projection and not for duplication, utitize a silver anti-halation undercoating that is removed during development. Reversal films are manufactured in different photographic speeds (exposure indices) ; common values are group 100 and group 50. These are ASA speed ratings given in accord-

TABLE III

Reversal Films

Universal Type[a]

Manufacturer	Code #	Trade name	Base	ASA exposure index (as negative)	Lines/mm rated resolving power
Eastman Kodak	5277	Super XX Panchromatic Safety	Blue	100	60
Eastman Kodak	5275	Super X Panchromatic Safety	Blue	50	55
Dupont	301	Superior II Safety Negative	Blue	50	70
Dupont	314	Safety Panchromatic Negative	Blue	25	80
Dupont	323	Orthochromatic Monitor Tube Recording Negative	Blue	50	80

Regular Type

Manufacturer	Code #	Trade name	Base	Antihalation backing	ASA exposure index (day)	Lines/mm resolving power
Eastman Kodak	5261	Super XX Reversal Panchromatic Safety	Clear	Silver	100	60
Eastman Kodak	5256	Super X Reversal Panchromatic Safety	Clear	Silver	25	75
Dupont	324	Telefilm Reversal Panchromatic Negative	Clear	Silver	40	80
Dupont	330A	Rapid Reversal Panchromatic	Blue	None	50	80
Ansco	1826–001	Hypan (200 ft.)	Clear	Silver	40	75
Ansco	1826–004	SSS Pan (200 ft.)	Clear	Silver	100	60

[a] The term Universal Reversal, encouraged by the Armed Forces during World War II, does not necessarily meet with the full approval of some film manufacturers (*e.g.*, Eastman Kodak) for commercial use.

ance with Z38.21–1947 "American Standard Method for Determining Photographic Speed and Exposure Index."

Table III is a listing of some of the available reversal films and their characteristics.

(2) Color-Reversal Film

The 16-mm color film that may be purchased in almost any photographic supply store is really a remarkable product. Although it is quite simple as far as the user is concerned, much accuracy is required in a large number of manufacturing and developing steps. Like black-and-white film, it is merely necessary for the user to load the color film in the camera magazine and give it the appropriate exposure.

Since the price of color reversal film customarily includes the cost of developing, the exposed color film is sent to the manufacturer for color developing. When the film is returned, the color is in the film itself. For projection, it is merely necessary to thread the film in a projector in the same way that black-and-white film is threaded.

At the present time only two manufacturers are marketing color reversal film in the United States—Eastman and Ansco. Both have been marketing color reversal film with the high direct-positive contrast characteristics suited to direct projection for a number of years; two types are available, one for use in daylight, the other for use in artificial light. More recently Eastman has marketed Kodachrome Commercial, a color positive original film not suited to direct projection that has low-positive contrast compared with Kodachrome Regular. The contrast characteristics of a Kodachrome color print from a Kodachrome Commercial original are quite similar to those of an original on Kodachrome Regular. Generally speaking, the list prices of competitive products are about the same; the professional user will not find the products interchangeable, however. No doubt many new processes and manufacturers will enter the competitive market in years to come, since the market is large and is growing rapidly.

The results obtained with both Kodachrome and AnscoColor are good when the films are correctly exposed. Because of the differences in manufacture and in processing, a side-by-side comparison of the two competitive films that have been used to photograph the identical subject matter under identical conditions will show marked differences in color rendering even though the detail-rendering ability of the two will be quite similar. The difference in color rendering will be particularly noticeable when subjects are photographed by daylight.

All color-reversal films are manufactured on the assumption that light of any color can be analyzed into three primary components. When the components are resynthesized, the original subject is reproduced in its original color. In practice, the accuracy of color reproduction is knowingly sacrificed to create results believed to be pleasing to the majority of viewers.

The theoretical background for color film and color photography is quite extensive and is beyond the scope of this book. Two outstanding texts are: *The History of Three Color Photography,* by E. J. Wall; and *The History of Color Photography,* by J. S. Friedman. It will probably be necessary to consult the former text in a library as it has been out of print for some time.

Figure 1B is a diagrammatic representation of a color-reversal film such as AnscoColor or Kodachrome. White light provides an exposure

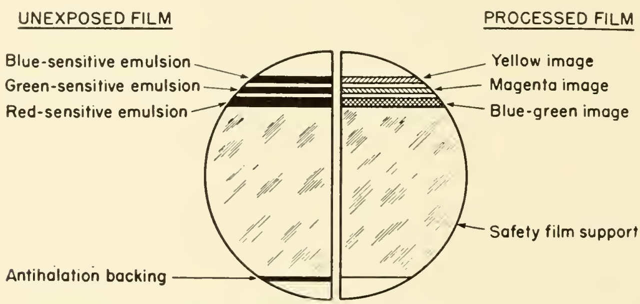


Fig. 1B. Cross section of Kodachrome film. This is a typical multi layer integral tri-pack color film.

in all three layers; blue light exposes the upper layer only; green light exposes the middle layer only; and red light exposes the lower layer only. (If there is no light there is no exposure.)

Practically, the film has no blue, green, or red filters. The method of analyzing the image into the three components and the manner in which these components are individually recorded will become apparent from the description that follows.

The upper emulsion layer of the film is sensitive only to blue. Green light and red light pass through it readily without affecting it. No blue light passes to either of the lower emulsion layers; a yellow dye is located between the top (blue-sensitive) layer and the middle (green-sensitive) layer to prevent its transmission.

The middle emulsion layer is sensitive to green light but is not sensitive to red light. Although it is sensitive to blue light, as are all silver emulsions, no blue light reaches it and there is therefore no exposure from blue light. Since it is sensitive to green light but not to red, only the green light causes an exposure in this layer.

The lower emulsion layer is sensitive to red light but is not sensitive to green light. Although like all emulsions, this layer is also sensitive to blue light, there is no exposure caused by blue light, since none reaches it. Thus, the lower emulsion layer registers only from the exposure by red light,

Color-reversal film has the customary antihalation backing on the base of the film and a hard gelatin antiabrasion layer over the top emulsion layer.

Color Developing. The film passes through a first developer in a manner similar to black-and-white reversal. Here all the emulsions are developed and images appear in each layer as negative black and white. A bleach dissolves the image formed by the first development and some fine-grained emulsion remains unaffected just as in black-and-white reversal processing. The film is given a second exposure (sometimes called re-exposure) in a manner quite similar to the re-exposure given to black-and-white reversal film.

In the second development, a dye of predetermined color appears along with the silver in each layer. The film is then put through a bath in which the silver is dissolved away, leaving only the dye images.

The top layer is now an image in a yellow* dye; the middle layer is an image in a magenta† dye; the lower layer is an image in a cyan‡ dye. Thus each layer provides a dye image in a color that is the complement of the color that exposed the layer. Where there was no exposure, all layers have the maximum quantity of dye and the film appears black. In the case in which a very bright white light provided the exposure, all layers have the minimum quantity of dye, and the film appears clear.

Color Reproduction. The film projector throws white light on the film. If blue light was the only light used for exposure of the film when it was placed in the camera, the top layer of the film is clear. The middle layer, being unexposed, is dyed magenta. The lower layer of the film, also unexposed, is dyed cyan. When the white light from the projector traverses the film, green rays are absorbed by the magenta (minus green) dye, and red rays are absorbed by the cyan (minus red) dye. The only portion of this white light that remains unaffected is the blue; in this manner the blue light used to photograph the original scene is reproduced by the film that is run in the projector.

The reproduction of green is accomplished in a manner similar to that for blue. If green light was the only light used for exposure of the film when it was placed in the camera, the middle layer is clear. The top

* Minus blue: yellow.

† Minus green: magenta.

‡ Minus red: cyan.

and lower layers, being unexposed, are dyed yellow and cyan, respectively. When the white light from the projector traverses the film, the blue rays are absorbed by the yellow (minus blue) dye, and the red rays are absorbed by the cyan (minus red) dye. The only portion of the white light that remains unaffected is green; in this manner the green light used to photograph the original scene is reproduced by the film that is run in the projector.

The reproduction of red is accomplished in a similar manner. If only red light was used to expose the film when it was placed in the camera, the lower layer of the film is clear. The top and middle layers, being unexposed, are dyed yellow and magenta, respectively. When the white light from the projector traverses the film, the blue rays are absorbed by the yellow (minus blue) dye, and the green rays are absorbed by the magenta (minus green) dye. The only portion of the white light remaining unaffected is red; in this way the red light used to photograph the original scene is reproduced by the film that is run in the projector.

TABLE IV

Color Reversal Films for Original Photographing

Manufacturer	Code #	Trade name	K color temp.	Lines/mm resolving power
For Direct Projection				
Eastman Kodak	5263	Kodachrome Daylight Type Safety color film	6100	75
Eastman Kodak	5264	Kodachrome Type A Safety color film	3450	75
Ansco	2827–004	AnscoColor Daylight Type (200 ft.)	—	—
Ansco	2827–007	AnscoColor Tungsten Type (200 ft.)	—	—
Not For Direct Projection				
Eastman Kodak	5268	Kodachrome Commercial Safety color film	3200	75

Since all colors are made up of these three components in varying degrees, any color appearing in nature can theoretically be reproduced.

Table IV is a list of some common color reversal films for original photographing.

(3) Positive-Type Dyed Film for Variable-Area Sound Originals

Early variable-area, 35-mm sound originals were recorded on ordinary release positive film of low resolving power (50 lines per millimeter) when double-system sound was first introduced in 1928 and 1929. When 16-mm sound was attempted using the same emulsions, the results were not satisfactory. Since survival of the 16-mm sound-recording equipment industry depended commercially upon improvement in sound reproduction, strenuous efforts were made to improve both the sound-recording machinery and the film.

Eastman 5372 is probably the best material on the American market for variable-area 16-mm recording. The film uses a nonhalation blue-dyed base of an acetate type that has low initial shrinkage, low ultimate shrinkage, and is quite accurately cut and perforated. The resolving

TABLE V

Positive Type Film for Variable Area Sound Recording

Manufacturer	Code #	Trade name	Base	Lines/mm rated resolving power
Eastman Kodak	5372	Fine Grain Sound Recording Safety Type 5372	Blue	150

power of the emulsion is rated at 150 lines per millimeter; values close to this can be realized in practice. The emulsion is blue-sensitive (color-blind)* and has excellent keeping qualities and shows but little change in exposure speed with age. Since it is a fine-grain emulsion, emulsion turbidity is quite low, resulting in relatively little image spread. The consistency of sensitometric characteristics from one manufacturing lot to another is quite high, indicating that the material is controlled well in manufacture. The future will no doubt see competitive materials appearing on the market as the demand for this class of film material increases.

Table V lists this common film for variable-area sound originals. It is often used in recording television picture images photographed from the face of a television program monitor tube.

(4) Negative Film for Special Purposes

As will be pointed out later (Chapter IV), 16-mm negative raw stock is rarely used for the original material for 16-mm release prints because

* "Color-blind" is a trade term meaning unsensitized for color.

it is almost impossible to edit and splice it with currently available equipment and methods without serious picture quality deterioration due to the lines that result from the encroachment of a splice upon the printed area of the film and the dirt, scratch, and smear marks accumulated in even very careful handling. Such marks are very noticeable because of the low average image density of negative film. If no editing of the original is required (as might be the case in the "reference recording" of a television transmission), negative film would be suitable. If subsequent transmission of the reference recording were planned, special negative raw stock made specifically for television transmission purposes would be desirable.

TABLE VI

Negative Films

Manufacturer	Code #	Trade name	Base	Exposure index	Recommended developing gamma	Lines/mm rated resolving power
Eastman Kodak	5242	Super XX Negative Panchromatic Safety	Blue gray	100	0.65	55
Eastman Kodak	5241	Plus X Panchromatic Safety	Gray	50	0.65	—
Eastman Kodak	5240	Panatomic X Safety Film	Blue gray	25	0.65	60
Eastman Kodak	5212	Infrared Negative Safety	Gray	—	0.65	—
Ansco	1822–004	Supreme (200 ft)	Gray	50	0.65	60

Note: See also Universal reversal films of Table III.

The use of negative for television transmission purposes has the well-known handling disadvantages with respect to a picture positive. As the image density is low, dirt, scratches, and abrasion marks that are unobservable in a positive become distressingly serious in a negative. The handling of negative requires extreme care; since such extreme care is rare, commercial operations are usually more satisfactory with positive image films.

Table VI is a list of some of the negative films available.

Duplicating Film Materials

A duplicating film is a film used in the process chain between the original film and the release print for the purpose of facilitating release

printing and/or preservation of the original film. Modern duplicating films are characterized by high resolving power and fine grain; under accurately controlled conditions of use it is possible to intercut a print from a 35-mm picture negative and a print from a dupe negative derived from a master positive printed from the original negative without any change in picture quality observable by other than highly trained observers. When modern duplicating films are suitably used, they cause very little quality degradation, such as increase in graininess, contrast change, or loss of detail either in the highlights or shadows of the picture.

A typical use of duplicating films is in the making of release prints from a black-and-white reversal original through the use of a dupe release negative. (Original reversal to dupe release negative to release prints.) Another typical use of duplicating films is in the making of 16-mm release prints from 35-mm picture negatives; this involves first the making of a 35-mm master positive of the original negative, next 16-mm dupe release negative, and last the release print.

(5) Dupe Negative—Fine Grain

Dupe negative film is a fine-grain negative-type film used to provide a negative aspect image when printed from a picture positive. Although dupe negative films are available in low resolving power types, these are obsolete; only fine-grain dupe negative film should be used. A typical film such as Eastman 5203 will have the following characteristics: a blue-dyed nonhalation base; fine-grain and relatively low photographic speed; and a panchromatic emulsion. Dupe negative film is customarily developed in a negative-type bath; the developing time is best kept short for the purpose of keeping graininess to a minimum. (The rated resolving power of Eastman 5203 is 110 lines per millimeter.)

Table VII is a list of the dupe negative films available.

TABLE VII
Dupe Negative Films

Manufacturer	Code #	Trade name	Base	Recommended developing gamma	Lines/mm rated resolving power
Eastman Kodak	5203	Fine Grain Panchromatic Duplicating Safety	Blue	0.65	110
Dupont	308A	Fine Grain Panchromatic Duplicating Safety	Blue	0.65	160

(6) Master Positive—Fine Grain

Master positive film is a fine-grain positive-type film used to provide a positive aspect image when printed from a dupe negative or from an original negative. Although low resolving power master positive materials are available on the market, they are obsolete; only fine-grain master positive film should be used. A typical film such as Eastman 5365 will have the following characteristics: a yellow-dyed ''color-blind'' positive-type emulsion; fine-grain; rated resolving power of 150 lines per millimeter; and quite low photographic speed. Master positive film is customarily developed in a negative-type bath; since the emulsion is inherently a high-contrast ''color-blind'' positive type responsive only to ultraviolet and blue, it is necessary to develop the film in a negative bath to bring the contrast of the master positive film within practical limits to provide a gamma product of unity when used with the dupe negative. (Theoretically, a gamma product of unity causes no change of contrast of an image regardless of the number of copying steps involved; this assumes no loss of resolving power in the process.)

Table VIII lists the master positive fine-grain available.

TABLE VIII

Master Positive Film

Manufacturer	Code #	Trade name	Base	Anti-halation dye	Recommended developing gamma	Lines/mm rated resolving power
Eastman Kodak	5365	Fine Grain Duplicating Positive	Clear	Yellow-dyed emulsion	1.40	150

Release Print Materials

(7) Release Positive (Black-and-White) Fine Grain

Release positive is film used to make release prints. ''A release print is a composite print made for general distribution and exhibition. . . .''* The film used is a compromise of print quality with laboratory print manufacturing cost; it is not the best quality print that can be made, but rather the best that can be made at a satisfactorily low price. Since both picture and sound appear on a release print, it is also necessary that the quality of neither shall be seriously jeopardized for the sake

* ASA Z22.56–1947, section 3.4.6.

of the other. Release print materials presently used are called fine grain and are rated at 90 lines per millimeter resolving power. Although it is recognized that improved picture and sound quality can be obtained by the use of finer-grained release print stock, *e.g.*, 150 lines per mm, significant increases with presently available materials would be quite costly because of the low photographic speed of such materials. Processing would require an increase in film exposure and a reduction in developing machine speed and/or printing machine speed. At the moment it may be doubtful if the increase in print cost caused by the reduction in quantity output can be justified by the amount of quality improvement realized in projection. In all likelihood, newer films will be evolved intermediate in speed and in resolving power between the present raw stock rated at 90 lines per millimeter and duplicating positive rated at 150 lines per millimeter. Although ordinary positive raw stock rated at 50 lines per millimeter resolving power is still manufactured, it should not be used for 16-mm release prints, since its detail-rendering ability is inferior. Typical fine-grain release print films are DuPont 605A and Eastman 5302.

Table IX is a list of the release print films available.

TABLE IX

Release Positive Fine Grain Black-and-White Films

Manufacturer	Code #	Trade name	Base	Recommended developing gamma	Lines/mm rated resolving power
Eastman Kodak	5302	Fine Grain Release Positive	Clear	2.5	90
Dupont	605A	Fine Grain Release Positive	Clear	2.4	100

(8) Color-Reversal Print Stock

Color-reversal print stock is film used to make copies; in most cases the copies are used as release prints. Color reversal prints are often referred to as dupes (or duplicates) ; in a strict sense the term duplicate is used only in connection with intermediate films to facilitate release printing. At present there is only one general grade of color reversal print stock on the market; this has a rated resolving power of 75 lines per millimeter and a resolving power realizable in practice of about 40 lines per millimeter. Generally speaking, there are broad color filter

overlaps in the layers of original color film between adjacent color ranges at the filter crossover wavelengths of 500 and 600 millimicrons, and narrow overlaps in color reversal print stock. Typical print stocks of this kind are Eastman 5265 and Ansco 832.

In a strict sense it may be said that there are no color reversal duplicating films* manufactured. For the present, film manufacturers seem to feel that the low resolving power of multilayer color reversal films (necessitated by the need for high photographic speed in the individual emulsion layers), and the color dilution and contamination that occurs because of imperfect optical filtering leads to such significant quality degradation per copying step that second generation copies are below the quality minimum commercially desirable. Much effort is being made to devise methods of duplicating that will bring second generation copies as far above the quality minimum as possible. The methods include improvements related to the films, such as (*a*) the use of black-and-white film for color separations (taking advantage of the higher resolving power of black-and-white duplicating film), (*b*) the use of a color dupe negative and color print (in which the developed color dupe negative has an inverted tonal aspect and the colors are registered as complements), and (*c*) improvements in other details.

Table X is a list of some of the color-reversal print stock available.

TABLE X
Color Reversal Print Stock

Manufacturer	Code #	Trade name	Color temp., K	Lines/mm rated resolving power
Eastman Kodak	5265	Kodachrome Duplicating Safety 5265	2900	75
Ansco	832	AnscoColor Duplicating Film	......	......

Note: Although the manufacturer does not provide ratings of color temperature and of resolving power, AnscoColor Duplicating Film will be found to have operating values comparable with Kodachrome.

(9) Reversal (Black-and-White) Print Stock

Reversal print stock is print stock used to make reversal prints. Most release prints are made on black-and-white release positive; reversal prints are ordinarily used when only a small number of copies of prints

* The term master is often used in the trade for a film made specifically for use in producing other prints or in facilitating the production of prints.

without sound is required. Reversal print stock (often called reversal duping stock) is consumed mostly by film manufacturers' laboratories and their agent laboratories; reversal work prints are often made with positive stock to reduce cost. The picture quality from reversal prints made on positive stock is ordinarily not as good as that made on reversal stock. A typical positive often used for reversal work prints is Ansco 2250, a positive film originally intended for variable-area sound recording. There is only one grade of reversal print stock regularly supplied by either Eastman or Ansco; Dupont does not market this material.

Table XI is a list showing the reversal print stock available.

TABLE XI

Black-and-White Reversal Print Stock

Manufacturer	Code #	Trade name
Ansco	198	Reversal Duping Stock

Note: At present there is little call for reversal duping stock on the open market.

(10) Miscellaneous

At the moment, television is having a marked accelerating effect upon the introduction of new film materials. The contrast, tonal scale, and resolving power characteristics of present-day television systems are markedly different from the comparable characteristics of motion picture systems. In brief, the contrast is different, the tonal scale shorter, and the resolving power relatively poor.

As the exposure and the processing procedures for films may be altered to fit any reasonable system condition of tonal scale and contrast, many successful efforts have been made to use available materials differently, as well as to provide completely new materials for television purposes. Both negative and reversal films are used to photograph original events for television, and television transmission of the original film or (more usual) prints derived from the original is now very common. It would be well for motion-picture-minded persons to remember that television systems are very versatile, and permit changes of system contrast by turning a knob, and also permit a change from positive television transmission to negative transmission by snapping a switch.

Reference recording of television transmissions is now quite common. In one method capable of a fair quality result, fine-grain sound recording safety film (EK 5373) is exposed by a cathode-ray monitor tube. Such

reference recording arrangements are capable of providing a film with either a negative or a positive image aspect with processing in a single positive bath. The use of a material of 150 lines per mm resolving power in a suitable manner does much to limit the image degredation that occurs in the transfer of the image from the electrical television system to the fixed image on a film.

Television film procedures are in a state of flux, and methods have not become sufficiently stabilized commercially to warrant detailed description. Users who are concerned would do well to keep in close touch with the professional film departments of film manufacturers if they wish to be kept abreast currently of the rapid changes in this dynamic field.

Since 1952 there has been a marked increase in the use of color negative-color positive materials. Although color negative, color positive, separation positive, color dupe negative and color reversal internegative materials are available for 35-mm film, only color positive film has been widely available in 16-mm. As manufacturing and processing control improves, such materials will become available in the 16-mm width.

General Comments on Available Films

Film emulsions are today of good and consistent quality. Their freedom from dirt and other occluded extraneous matter is remarkable; almost all the dirt and foreign matter found on today's films are acquired during developing and use. Not only is improvement in the film itself desirable, but also improvement in the processing, so that a much greater percentage of the quality potential will be realized. Much progress can be made in improving print quality if the characteristics of films are studied and processes of exposure and development accurately controlled to make best use of the quality potential of the films used.

Selected References

''Photography'', *Encyclopedia Americana*, Vol. 22, 1–7 (1947).

Mees, C. E. K., *The Theory of the Photographic Process.* Macmillan, New York, 1944.

James and Higgins, *Fundamentals of Photographic Theory.* Wiley, New York, 1948.

Roebuck and Staehle, *Photography Its Science and Practice.* Appleton-Century, New York, 1942.

Clark, W., ''Cellulose—Photographic Film'', *Dictionary of Applied Photography*, Vol. 2, 4th ed., p. 446 (1938).

Matthews, G. E., ''Chemistry of Photography,'' *The Complete Photographer*, Issue 11, pp. 702–718 (1941).

Corbin, Simmons, and Hyndman, ''Two New Eastman Fine-Grain Sound Recording Films,'' *JSMPE, 45*, 265 (Oct. 1945).

Moyse, H. W., "Dupont Fine-Grain Sound Films Types 232 and 236," *JSMPE, 45,* 285 (Oct. 1945).

Goetz and Brown, "Light-Scattering and the Graininess of Photographic Emulsions," *JSMPE, 39,* 375 (Dec. 1942).

Talbot, R. H., "The Projection Life of Film," *JSMPE, 45,* 78 (Aug. 1945).

Calhoun, J. M., "The Physical Properties and Dimensional Behavior of Motion Picture Film," *JSMPE, 43,* 227 (Oct. 1944).

Fordyce, C. R., "Improved Safety Motion Picture Film Support," *JSMPE, 51,* 331–350 (Oct. 1948).

Physioc, L. W., "Photographic Emulsions," *JSMPE, 19,* 913 (July 1932).

Additional references may be found in the following JSMPE indexes:

July 1916 to June 1930

January 1930 to December 1935

Index 1936 to 1945

CHAPTER IV

Making 16-Mm Originals

Size of Originals for 16-Mm Release Prints

As mentioned earlier, 16-mm release prints may be manufactured from a variety of different film sizes as originals. Dimensions have been standardized to the point where it is possible to make 16-mm release prints from three sizes of picture (35-mm, 16-mm, and 8-mm), and from either of two sizes for sound (35-mm or 16-mm). Up to the present there is no commercially satisfactory 8-mm sound available.

The greatest volume of release prints has been produced by optical reduction from duplicates of 35-mm originals. Since the production of 35-mm films has been described at some length in other texts and in engineering journals, such as the Journal of the Society of Motion Picture Engineers, such data will not be repeated here.

A smaller yet important volume of release prints has been produced from 16-mm originals. Kodachrome has played an important part in encouraging 16-mm growth for industrial, education, and other non-amateur purposes; no integral tri-pack color film of this kind has been available for equivalent 35-mm use. The combination of 16-mm Kodachrome picture with 35-mm negative sound track has been fairly common, but the inconvenience of handling 35-mm film (which is inflammable as well as clumsy) simultaneously with 16-mm film (which is compact and slow burning) will mitigate against further rapid growth—especially when 16-mm sound-recording apparatus of good reliability becomes more widely available in the near future.

While 8-mm picture has often been used for special purposes to provide 16-mm release prints, such use is the exception rather than the rule. The emphasis of war standardization concentrated heavily upon 16-mm, and it is only logical to expect that such standardization will have far-reaching effects in further expanding the use of the 16-mm size. Rapid improvement of quality in 8-mm picture and very wide amateur use can be reasonably expected, but the far lesser extent of 8-mm standardization compared with that of 16-mm will act as a handicap in its growth for professional uses.

Prospective Volume of 16-Mm Films

Major increases in the volume of 16-mm release prints made from 16-mm originals can be confidently expected. The vicious circle of "no films, no projectors" has been broken by the training and other film activities of the Armed Forces in the United States and also in other parts of the world. During World War II, along with Lend-Lease deliveries of American-made P-39 Airacobra fighter planes to the Russians, sound films describing their servicing and maintenance were supplied. Although the earlier films were merely copies of the films delivered to the American Air Forces, later films used Russian sound tracks and other editing modifications to produce a Russian version.

Conservative estimates indicate roughly a fourfold increase in the number of 16-mm sound projectors in use in the United States as a result of World War II. The number of hours' use per year per projector has also risen markedly. Well over 500 million feet of 16-mm film was manufactured and used in a single year during the war interval. Although much film and many projectors are worn out or are obsolete and should be scrapped now that their war uses have been satisfied, the volume of such material remaining is still far larger than that of all films and all projectors in existence prior to the war. Efficient utilization of such material is desirable if the nation is to realize the maximum benefit from its large war investment.

Even though most efficient utilization of the surplus films and projectors may be made, large gaps will still remain in our civilian educational and training system. Production of a large number of subjects as parts of integrated teaching and training programs is still badly needed, as are improved projectors to show such new films. Technology was accelerated by the War to a greater extent than at any other time in our earlier history. An urgent need now exists to spread rapidly and widely the knowledge gained from this growth and to capitalize upon the technological advances made.

Direct 16-Mm Production

Single System vs. Double System Sound Recording

As in 35-mm, 16-mm sound film may be made by either the single system or double system method. In the single system method, the sound is usually recorded at the same time that the picture is taken and recorded photographically upon the sound track area of the same film

Single system recording is rarely used for professional 16-mm production because:

(*a*) It is rarely necessary or even desirable to record the sound which actually forms part of the action being photographed. This is especially true of 16-mm non-entertainment films.

(*b*) It is impracticable to edit single system film in a satisfactory manner.

(*c*) Sound quality is decidedly inferior because the resolving power of picture original film is usually much lower than that of film designed especially for sound recording.

In the double system method, the sound is recorded on a separate film, and usually not at the time at which the picture is taken. The double system method permits the use of the best available raw films for both picture and for sound without serious sacrifice of quality for either. It is for this reason that the double system method is used almost exclusively for all theatrical 35-mm films as well as for commercial 16-mm films.

Combinations of both the single and double system methods are occasionally used. These combinations are intended for special purposes and account for an insignificant fraction of all film consumed.

The 16-Mm Picture Original

Film for the 16-Mm Picture Original

While 16-mm film has much in common with 35-mm theatrical film, there are certain features which have no counterpart in the larger size. The 16-mm picture original is an excellent example.

When a 35-mm black-and-white positive is desired, it can be obtained from a 35-mm original only by printing from a negative, since there is no 35-mm reversal film commercially available. In 16-mm, however, direct positives such as black-and-white reversal and color reversal are the rule rather than the exception. The attempt to use the terms original and negative interchangeably in the 16-mm medium is not only confusing but definitely in error although the terms are quite correct in 35-mm where they are customarily so used.

While the apparently obvious means of obtaining a 16-mm black-and-white print would seem to be the printing of a 16-mm negative, this method is usually the least satisfactory when good quality prints are required from assembled (edited) originals. The dirt and scratches accumulated in even meticulous handling of 16-mm original film are quite objectionable when negative is used. In addition, annoying light flashes appear in the print wherever a splice occurs in the negative.

Where best over-all print quality is the objective, the most suitable materials for 16-mm originals are reversal materials. Reversal materials when handled carefully show little or no evidence of dirt, scratches, and light flashes that are almost unavoidable even with carefully handled negative. Reversal always produces a reduction of grain size; it is inherently a fine grain process. In black-and-white reversal, the larger grains of the film emulsion, being most sensitive to light, are most affected by the first or negative exposure. These larger grains are then removed in the bleaching operation that follows the initial development, leaving the smaller grains of the emulsion exposed by the second or positive exposure to make up the final image on the film. In color reversal, the final image is made up essentially of dyes which are, to a major degree, grainless; the initial development and bleaching operations are essentially the same as for black and white.

The advantages of direct positive materials are now so pronounced that negative-type materials have been abandoned in most applications where a large number of print copies from an edited original is required. Some independent laboratories are reversing positive film for the making of work prints and duplicates but the volume of this work at the present time is not large when compared with release printing.

Consistency of Picture Quality for the Picture Original

Consistency in picture quality is extremely important for an individual, group, or organization engaged in the making of motion pictures. Since a copy can never be any better than the original from which it was made, deviations in quality in the original are ordinarily aggravated by the release print manufacturing process; the result is poor quality on the projection screen.

Strangely enough, the importance of consistency of quality seems to be little recognized before the original is photographed; too often the film laboratory is called upon to "save" an original because of lack of care or knowledge in the making of the original. "Saving" a film is really a thankless proposition; the result at best is only marginal. Every time an owner views a release print from a "saved" film, he wonders what he might have done to avoid his dilemma and wishfully thinks about "the film that might have been." Such experiences on the part of film producers or makers point out quite forcibly that a laboratory cannot bring out detail in the copying process that does not exist on the original film. If that were accomplished, it would be magic and not film processing.

To accomplish consistency in the picture original requires consistency in three important particulars:

(*1*) Consistency in the film.
(*2*) Consistency in its exposure.
(*3*) Consistency in its processing.

Film and Its Consistency. Film and its consistency has been discussed in some detail in an earlier chapter. The most consistent original materials today for 16-mm are integral tri-pack color films; this is true of both Eastman and Ansco products. As a practical matter it is difficult for a user to be concerned with film consistency without being concerned with processing consistency; on this count also the integral tri-pack color films are definitely superior.

In general, manufacturers of films do not release information to users on variations in quality from lot to lot of manufactured raw film; they do, however, keep accurate and extensive records of such variations together with data on the practical effects of such variations upon the usefulness of of the finished product. As described in the previous chapter on film, normal manufacturing variations do occur; there is no magic in the manufacture of sensitized materials that would exempt film from the laws governing the statistical quality variations of manufactured products. For most purposes, the variation in quality within a roll of film, or the variation in quality from roll to roll of film of a particular lot number is not important, while the difference from one lot to another is quite important. For this reason an accurate picture film test exposure and log book is just as important for maintaining picture quality as a similar log book is for maintaining sound quality. Fortunately, the variation from roll to roll and the variation from lot to lot of Kodachrome, for example, is relatively so small that if picture exposure variations would be of like order, there would be no such thing as a really bad original in conventional films. Unfortunately, most of the inconsistency occurs in the exposure of the original film.

Exposure Consistency. Exposure and its consistency depends upon consistency in the readings of a measuring light meter, consistency in the manner of its use, and consistency of the judgement used in transferring the data so obtained into the aperture setting for the lens used. For most uses, calibration of the light meter once a month is sufficient to detect any loss in sensitivity. When such meters are calibrated, all previous calibration data should be available so that the magnitude of the loss in sensitivity can be judged relative to the previous calibrations.

Consistency in the manner of use depends upon the training and habits of the photographer. Generally speaking, if the photographer consistently measures highlight areas of the picture and keeps the shadow illumination contrast not greater than 4 to 1 with respect to the highlight illumination, the result should be acceptable, and with a little experience, should be good. In practice, the measurement should be made of light reflected from a reference test object which may be a piece of new bristol board free of dust, smudges, etc. Consistency in the judgment used in transferring data so obtained into the aperture setting is probably the largest potential source of error. Corrections are required for changes in film speed, in camera speed, and in differences between the actual light transmission of the lens and the theoretical light transmission calculated from the "*f*" stop markings on it, and other factors. In many cases in which results are inconsistent, flagrant causes are usually to be found in lens transmission differences and in errors in iris adjustment as well as in camera speed differences and deviations.

Processing Consistency. Processing accounts for another potentially serious source of variation. The processing of Kodachrome is probably the most consistent processing service available. Despite its excellent control, noticeable differences will be apparent in the side-by-side projection of pieces of the same film developed in different laboratories or in the same laboratory at different times. Fortunately, side-by-side comparisons are rarely required. The processing of reversal films is not so consistent; too often factors other than sensitometric control (such as excessive hypo and poor film drying, etc.) complicate matters and further encourage a decided preference for the color film.

Black-and-White Reversal Materials

Present-day reversal materials still give the impression that they are intended for the amateur, who, according to a current fallacy, likes his film "as fast as possible and as hard as nails." In original reversal materials today there is still a big need for a low-contrast, long-reproduction-scale material, since there is no such thing on the photographic market and we have been struggling along without it for ten years or more. Ansco did manufacture a film called "Old Type Superpan," which was a long-scale material of beautifully low contrast, but it was unfortunately withdrawn from the market when the faster emulsions of the "Supreme" type apeared. The film manufacturer who supplies such material and incorporates in it the new emulsion improvements of recent years as to

grain reduction and speed will not only earn the blessings of a long-suffering professional market by reopening wide fields of usefulness, but should also find it profitable. All finer grained reversal emulsions today of the high-contrast type.

When reversal films were first marketed, their users were almost entirely amateurs. Since many of the amateur films received by the manufacturer's laboratory for development were underexposed, it was felt that a sacrifice of gradation for the sake of photographic speed was well justified. At the time the "Old Type Superpan" was withdrawn from the market, the number of professional users of 16-mm film was quite small compared with other users. The vocal complaints received from casual amateurs concerning the absence of "snap" (contrast) were impressive in number and effectively drowned out the more studied praises of a relatively small body of quality-conscious amateur and professional users.

With only high-contrast reversal materials left on the market, it was necessary for the serious amateur and professional photographers to reduce materially the lighting contrast customarily used for studio photogaphing with 35-mm negative. To avoid production difficulties, laboratories recommend flat lighting with high-light to low-light ratios in the photographed scene no greater than 3 or 4 to 1. Most reversal materials today are of the short-scale, high-contrast type.

Regular Type Reversal

Both Eastman and Ansco operate company-owned or contract processing stations to develop reversal film. These reversal films are somewhat different from negative; not only is the emulsion slightly thicker, but a silver undercoating is used that remains on the film as a black scum when the film is developed as a negative, but which is removed during the bleaching operation when the film is developed as a reversal. A film intended for reversal developing that is not suitable for negative developing is called a regular reversal.

Universal Type Reversal

Since DuPont preferred to market film for developing by laboratories that were not company-owned or under company contract, the sale price of DuPont film ordinarily does not include developing. Accordingly, that firm found it advantageous to market film of the universal reversal type; this is designed for use either as a reversal or as a 16-mm negative.

When universal film is to be used as a reversal, the exposure is increased (usually 2×) compared with the exposure it would be given as a negative. Fortunately, a convenient system of speed ratings known as the ASA (American Standards Association) Exposure Index* simplifies the manner of expressing photographic film speed.

Since the advent of World War II, the importance of the universal type of reversal film has grown at a very rapid rate. For special purposes, such as the gun-sight-aiming-point (GSAP) cameras that were used to record the firing of machine guns and other weapons of an airplane, there are occasions when the developing of film as a negative had decided advantages. Interchangeability is effected and warehousing problems greatly simplified if the universal type of reversal replaces regular reversal and negative types in such applications.

Generally speaking, reversal materials of the smallest exposure index practicable should be used as orginal materials, because they are the least grainy. Even with the very best processing at all steps, graininess in prints is always a factor that must be kept to an absolute minimum. Graininess in an original is always aggravated by the release printing operation; for this reason materials with a reversal exposure index of the order of 25 or lower are definitely preferred. Materials of higher index should not be used if it is at all possible to avoid them since their graininess is usually noticeable in the original and becomes quite objectionable in the release prints produced from such originals.

Simple graininess comparisons can readily be made with a conventional high-quality projector, with a 750-watt lamp projecting test pictures upon a good, clean matte screen approximately four feet wide. All tests viewed should be observed from the center of the screen at a distance equal to 2× screen width. Any new commercial projector with a good gate and a good lens is suitable. Such graininess tests should never be conducted with production film, because of the scratching and other damage that would be certain to result from handling. Tests should be original photographs of identical subject matter, properly exposed and developed, and projected for comparison at a single showing. Better graininess comparisons can of course be made with more elaborate arrangements, such as two interconnected identical machines projecting images side by side on the same screen; for most purposes the more elaborate arrangements are not justified.

* ASA Z38.2.1—1947, "Photographic Speed and Exposure Index, Method for Determining."

Color Reversal

The first successful color reversal 16-mm material to appear on the American market was Kodachrome—introduced commercially by the Eastman Kodak Company in 1935. Since its introduction, its use has grown by leaps and bounds.

Multi-layer color film with three separately sensitized emulsions coated in succession on to the same support was the subject of intensive study for many years; it was first described by Schinzel in 1905. At that time there were no sensitizing dyes available which would remain in only one of the layers, nor was a means known for forming a satisfactory dye image in each layer separately. In 1913 Fischer patented the coupling development process, but he also found it difficult to keep the couplers in their separate layers.

Years later Mannes and Godowsky disclosed how to develop the separate layers to give differently colored dye images, and with the invention of improved "non-wandering" optical sensitizers, the Kodachrome process was developed. I. G. Farben (Agfa) in Germany invented color-forming couplers that could be placed in an emulsion and would not wander to an adjacent layer; such couplers are used in AnscoColor film.

Because the color separations that are effected in an integral tri-pack film such as Kodachrome or AnscoColor result in a considerable loss of light, individual emulsions of very high speed (and consequently coarse grain) are required to obtain a film of even relatively low speed. Thus, individual emulsions of exposure index of the order of 50 are needed to obtain an integral tri-pack of effective exposure index of 10 or 12. However, if exposure is controlled accurately, excellent results can be obtained with either Kodachrome or AnscoColor film due to the excellence of manufacture and of processing control exercised by their respective manufacturers despite significant color differences between them. Unfortunately the dyes in Kodachrome and AnscoColor are fugitive to some degree.

The fact that such integral tri-packs make excellent original materials for black-and-white release prints has been insufficiently recognized in the past. Critical professional film users have become aware of this and are turning to color reversal film as the original material for their black-and-white prints. Color reversal film as marketed has appreciably lower contrast than any finer grain reversal films now on the market and its users find it well worthwhile despite its higher cost and lower speed. The contrast and gradation of the Daylight (regular) and of the Mazda (Type A) color reversal films are similar; the contrast of Kodachrome

Commercial* is appreciably lower and provides excellent low-gamma gradation. Comparative tests should be made with all possible types using the daylight type film as the reference. From a production viewpoint, the slower speed of color tri-pack films is a serious handicap because of the appreciably larger amount of lighting equipment necessary. However, its users point out that the excellence of emulsion control and of processing control of color reversals is relatively so high that consistently better black-and-white prints can be obtained from Kodachrome or AnscoColor originals than from black-and-white reversal original materials. The advantages inherent in black-and-white reversal materials are not realizable in practice at present, due mostly to inconsistent processing control. The differences in production costs due to the higher price of color raw stock can be ignored in view of the processing control advantages obtained.

Color Film Classes

In general, there are two classes of integral tri-pack color films: one class that is intended primarily for projection after the film is processed, and the second class that is not intended for projection after processing but rather as a master film to be used for the printing of copies. The latter class is comparatively new—introduced by Eastman Kodak in 1946.

In the former class, there are two types of integral tri-pack films: the daylight type that is intended for use in daylight (color temperature 6100 K) and the artificial light type intended for use with #2 Photofloods (color temperature 3450 K). The difference between the two is one of color balance; as daylight has appreciably more blue light (in the 400-to-500-millimicron range) and somewhat more green light (in the 500-to-600-millimicron range), it is apparent that compensating changes are made in the relative speeds of the three emulsion layers. Thus, the sensitivity of the blue-sensitive upper layer is appreciably lower for daylight film than for artificial light film, and the sensitivity of the middle green-sensitive layer is somewhat lower for daylight film

* It is usually advantageous to underexpose Daylight Kodachrome and Type A Kodachrome about one-half light stop for the purpose of obtaining better shadow detail in commercial duplicates. Underexposure of Kodachrome Commercial cannot be similarly recommended as it becomes noticeably grainy when it is appreciably underexposed. The increase in graininess with underexposed Daylight Kodachrome and Type A Kodachrome, if it occurs, is usually imperceptible.

than for artificial light film. If the same subject could be photographed on both types of film with correct lighting for each, the result would be substantially the same in projection.

Because of the higher blue-sensitivity and the higher green-sensitivity of the artificial light film as compared with the daylight film, it it possible to reduce the incident light in the blue and green ranges by the correct amounts with a filter when photographing subjects in daylight with artificial light type film in the camera. Since a Kodak Wratten #85 filter is intended to do just this by merely reducing the effective color temperature, the exposure index for the film remains the same as for photographing with artificial light without a filter. This simple expedient is quite satisfactory for conventional photographing; where more accurate rather than pleasing color rendition is required, more involved corrections may be needed. These usually comprise a set of relative intensity measurements in the blue, green, and red color ranges and the selection of suitable filters indicated by the measurements.

Scenes photographed on cloudy days at high altitudes, distant scenes with haze, and snow scenes usually have excessive blue and often appreciable ultraviolet present in the light. Since ultraviolet records as blue on the film (adding to the excessive blue already present), a filter is needed to remove the ultraviolet, and, in extreme cases, some of the blue. The Kodak Wratten #1A Skylight Filter is useful with daylight type color film outdoors in open shade under a clear blue sky where pictures without a filter would be too bluish; occasionally it may be useful on an overcast day for distant scenes, sunlit snow scenes, aerial photos, and mountain views. The Kodak Wratten #2B absorbs radiation shorter than 390 mμ; it is useful for the bluest of such scenes.

If a distant scene is photographed with a Kodak Wratten #85 filter, and artificial light type film is exposed with daylight, no filter similar to the Kodak Wratten #1A is needed, since the Kodak Wratten #85 effectively absorbs rays shorter than 380 millimicrons.

In general, it is preferable to use daylight-type color film in daylight and artificial light type film (type A) with photoflood illumination. Because Wratten #85 filter with artificial light type film does not alter the color temperature relationship in the exact manner that natural light changes, daylight-type color film will usually give better color rendition than a Kodak Wratten #85 filter with artificial light type film, particularly when photographing on overcast days. Daylight-type film is also preferred, because its dyes are somewhat less fugitive than those

of Type A. Should the Kodak Wratten #85 filter be used from time to time, it is a good idea to check it, since the dyes used in its manufacture are only moderately stable.

While is is possible to use daylight-type film in artificial light if Kodak Wratten #80 filter is used over the camera lens, this arrangement is not recommended because the effective film exposure index of the combination is reduced to less than half of its usual rating without any compensating advantages.

A great deal of experience has been gained in duplicating Kodachrome and AnscoColor within the last 10 years; most originals used have been of the type intended for projection rather than for duplicating. Recently, the second class of material was introduced by Eastman Kodak; this is known as Kodachrome Commercial, and is designed for a color temperature of 3200 K. This new film is designed for appreciably lower contrast in addition to the different color temperature. When duplicated in a continuous contact printer on Eastman Color Duplicating Film (code #5265), it is designed to provide a copy with color and contrast characteristics quite similar to an original made on Type A Kodachrome (code #5264).

Although photoflood and photospot illumination is adequate for the amateur and for noncritical professional uses, it is often not satisfactory for critical professional users because of the lack of constancy of color temperature during the normal lamp life. Broadly speaking, as a photoflood or photospot burns, there is not only a material change in color temperature due to filament evaporation, but there is also a change in spectral distribution characteristic caused by bulb blackening. This is especially noticeable if the lamps are used to burn-out.

Kodachrome Commercial is intended for 3200 K illumination; this is best obtained from 3200 K type lamps which are manufactured in the United States by the major lamp manufacturers especially for photographic purposes. Filters are commercially available for use with these lamps to increase the color temperature from 3200 K to 3450 K for illumination of subjects to be photographed with either Kodachrome Type A (indoor type), or AnscoColor (indoor type). Filters are ordinarily considered unnecessary with Mazda CP lamps (3380 K); for critical work, correction to the 3450 K rating of the Type A film may be required. Data on such filters may be obtained from both lamp manufacturers and from film manufacturers. The manufacturers of lamps can ordinarily supply suitable holders for the use of such filters.

Color Negative Film

For conventional uses, color negative has not been available in the United States in the 16-mm size despite the fact that it was widely used in Germany prior to World War II (Agfacolor, 35-mm size). It is probable that it will not be marketed since negative can not be recommended because of the excessive splice marks, dirt, and scratches appearing in the release print as a result of negative editing, this handicap also occurs with black-and-white negative.

Color Duplicate Negative Film

The use of the direct-positive, dupe-negative, release print technique so common in 16-mm black-and-white film copying, has not yet acquired commercial acceptance in color copying, partly due to the relatively large order of magnitude of the resolving power losses encountered with multi-layer integral tri-pack color films. Ansco will undoubtedly offer such materials to the 16-mm market as it has to the 35-mm market; when the market is ready, it is likely that other manufacturers such as Kodak and Dupont will do likewise. It should not be very long before the many advantages of the duplicate negative technique can be utilized in color as it is in black and white. Although it will call for a considerable "tightening up" of processing control, it will be well worth the effort, and laboratories that are progressive enough to grasp the opportunity to do an excellent job should reap generous rewards for their efforts. For the present, the resolving power losses of the over-all copying process are considered excessive, and film manufacturers are not encouraging such duplication in 16-mm.

Exposure of Original Reversal

The instructions for properly exposing both black-and-white reversal film and color reversal film are alike in many respects. Overexposure is to be studiously avoided; when there is doubt, it is preferable to deliberately underexpose by an additional one-half light stop. Reversal originals that are slightly underexposed (approximately one-half light stop) provide the maximum tonal range in release prints regardless of whether or not they are in color, or whether the release prints are to be made in color or in black-and-white. An original that is even slightly overexposed or one that is underexposed by more than $1\frac{1}{2}$ light stops should be discarded as unsuitable for high-grade duplication; there will

be excessive loss of highlight or of shadow detail if such an original is used for release printing.

In order to keep exposure within these relatively narrow limits there must be an understanding of the limitations of film and of equipment; results of the sort required cannot be achieved with the haphazard methods that were common in many picture-making circles before World War II. All variables in the process must be known and taken into account; it is not safe to *assume* any given element of the photographic process to be satisfactory. (Exposure accuracy and a limited highlight-to-lowlight brightness ratio are especially important with all reversal films designed for direct projection.)

Measurement of Exposure

Correct exposure is usually the result of good judgment tempered by experience and used in connection with a reliable instrument or instruments whose limitations are known and understood. There is no exposure meter or other generally available instrument that automatically indicates correct exposure in the absence of an intelligent interpretation of the results.

Exposure-indicating and measuring devices are wide in variety; of these, the photoelectric type is not only the most widely used but also the most reliable and subject to the least amount of error. All photoelectric types consist essentially of:

(*1*) A light collector.

(*2*) A photoelectric cell—usually of the barrier or the photovoltaic type.

(*3*) An indicating microammeter calibrated in either light units or equivalent photographic exposure data.

For photographing in the outdoors, the American Emergency Standard Photographic Exposure Computer ASA Z38.2.2–1949 is a useful rough guide. It is designed to apply to negative films used in land, marine, and aerial photography, and utilizes to a considerable extent the rather wide exposure latitude available in negative film. The computer relies on the judgment of the user in properly classifying the scene to be photographed, and with a certain amount of experience can be satisfactory for even the more limited latitudes of reversal films. When first used, however, it should be checked against a photoelectric type of exposure meter when the scene is photographed, with the developed film to be viewed as a check. Even a few frames of the test at

the end of the roll will be of invaluable assistance in aiding the photographer to judge future exposures, but viewing all the material photographed is still better.

Photoelectric exposure meters are of two general types:

(*1*) The reflected-light type, which includes the General Electric, Weston, and most other photoelectric meters.

(*2*) The incident light type, of which the Norwood photoelectric meter is typical.

Since the amount of light reflected from each object in the photographic field is different, the amount of exposure required is determined by which object or portion of the field is to be emphasized.

More words have been written about correct exposure and how to obtain it than possibly any other aspect of photography.

Although films have been improved tremendously in all respects in recent years, the latitude of the best material still falls far short of that of the eye. The eye has one feature that has never been applied to cameras with equivalent success: as the mean brightness of the scene changes, the iris of the eye automatically changes the total light flux admitted.

In outdoor photographing it is not unusual for the brightness contrast range of a scene to exceed by a wide margin the exposure range of the film. In general, an attempt is made to reduce the brightness contrast range by increasing the brightness in the shadows with reflectors or booster lights. Beyond this point, the brightness contrast range of the scene and the exposure range of the film are made to coincide by adjustment of the iris diaphragm of the camera lens. Other refinements of this basic procedure depend on the number of light measurements and the manner in which they are made. A further minor adjustment of reflectors or booster lights may be required to accomplish the desired effects.

In indoor photographing, lighting should be so arranged that the brightness contrast range of each scene is well within the exposure range of the film. For reversal films—both color and black and white—it is a safe procedure to limit this range to about 4 to 1 to avoid the necessity of later discarding film because of washed-out highlights or blocked-in shadows. Experience will no doubt indicate that a slight increase in range is permissible; the extent of this increase will probably depend more upon the photographer's control of the lighting than upon any other variable factor.

It is well known that all camera lenses cover an angular field that is very narrow with respect to the angular field of the eye; a 1-in. lens, for

example, covers a half angle of 22°. The angle covered by the lens is dependent on the focal length. Shorter focal lengths cover proportionately larger angles than longer ones. It would seem that some form of measuring device that receives light through the camera lens and is built

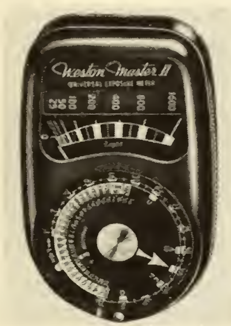


Fig. 2. Weston master II universal exposure meter. This is a high-quality two-range instrument of the reflected light type. This instrument measures reflected light in candles per sq. ft. on two instrument scales, 0–1600 and 0–50. The scale shown is the high range; in this position a hinged light-attenuating baffle on the rear of the instrument is snapped into place over the light-entrance aperture. When the baffle is released and snapped into the catch at the other end of its hinge travel, it is removed from the light path and the scale is automatically changed mechanically to the low range, 0–50.

Fig. 3. Weston model 9925 invercone incident light adapter for the Master II universal exposure meter. The adapter consists of two parts, and integrating cone (shown on the left), and an auxiliary multiplier that is a light-attenuating filter. To make incident light readings on the low range of the exposure meter, the light-attenuating baffle is released and locked in position out of the way, and the integrating cone snapped in place over the light-entrance aperture. To make incident light readings on the high range, the auxiliary multiplier is first snapped into the light-entrance aperture replacing the light-attenuating baffle, and the integrating cone snapped into place over the multiplier. The high range scale is then automatically returned to view.

as an integral part of the camera might be a suitable arrangement. This arrangement was common in pre-war European still cameras, but has not been used in American-made motion picture equipment. Standard reflected light type exposure meters have an acceptance half angle of 25° (ASA Z38.2.6–1948).

Both reflected light type and incident light type exposure meters have their respective advantages and disadvantages; a good cameraman can form the habit of using either with consistent results of superior quality. The lower priced, reflected light type is to be preferred for reasons quite apart from theoretical considerations. Prior to World War II, exposure meters were fragile instruments that had to be handled very delicately; since such meters were neither rugged nor reliable enough for military use, the ASA War Committee on Photography and Cinematography (Z52) standardized an improved instrument to correct the shortcomings of the older meter. The calibration reliability and ruggedness of the War Standard Exposure Meter is now so high that each instrument may be bounced around in a tumbling barrel with little or no change in readings as a result of this rough treatment. (ASA Z52.30–1944 describes the Abuse Testing Mechanism.) Such mechanical ruggedness and calibration reliability over periods of time measured in years rather than in hours or days are prerequisites to correct exposure measurements. Any meter used should be guaranteed by the manufacturer to meet the tests of Z52.30 or its equivalent; instruments not so guaranteed may be considered nonstandard and should be avoided as unreliable. Because of the distinct advantages to both reflection and incident readings, a single compact instrument to provide both in a simple yet accurate manner would be a boon to the serious cameraman. Figure 2 is a photograph of a Weston Master II Universal Exposure Meter. As a step in the direction of supplying both functions in a single instrument at reasonable cost, Weston now has available an incident light adapter called the Invercone Model 9925 that may be used with any Weston Master Universal Exposure Meter such as the Model 715 Master or the Model 735 Master II. The adapter consists of two parts, an integrating cone and an auxiliary multiplier. The price of this adapter is only some 10% of the cost of the meter proper. Figure 3 shows the Weston Invercone Light Adapter. General Electric has recently marketed a combination instrument; in this instrument all components are built as integral parts.

Actinic Value of Exposure

Although it has been pointed out repeatedly in the past, the warning that lights of different color temperature should never be mixed when photographing in color still bears emphatic repetition. For *all* indoor lighting it is well to assume that the subject is being lighted for color photographing. In this manner the cameraman and his associates get

into the habit of lighting for color; should black-and-white be desired, it is then necessary merely to reduce the exposure level used.

Color reversal as original film is to be preferred to black-and-white reversal because of the more precise control exercised in developing; this practical advantage far outweighs the possible theoretical advantage of somewhat better grain characteristics. The graininess advantage of reversal is likely to remain unrealized commercially because of the far wider tolerances customary in black-and-white reversal developing and because of the large haphazard nonprofessional interest that still exists.

Another advantage of photographing the original with color reversal film is that much subject matter has additional significance when seen in color. Once the color original exists, it is possible to make a small percentage of release prints in color if desired, while the remaining prints can be made in black-and-white.

As one example, a picture on first aid may be used in black-and-white for general study, but in a limited number of cases where greater realism is needed for clinical study, color prints may be used.

When photographing the original with black-and-white reversal film, uniform actinic quality is still desirable, since variations in color temperature of the lights give rise to variations in contrast of the original film because of the variations in film gamma with actinic quality of the exposure. Another important consideration also is the fact that exposure meters do not register equal amounts of all colors equally. The effective exposure on the film can vary rather widely in that the color sensitivity of the film may not match the color sensitivity of the exposure meter. New meters better adapted for color photographing will doubtless be marketed in the near future.

When lamps, receptacles, and cables are made up for use in indoor photographing, it is always good practice to provide at each fixture or lamp a test outlet into which a reliable test voltmeter may be plugged for testing the voltage across the lamp. If the difference between the rated lamp voltage and the voltage as indicated by a reliable meter is greater than 3 to 5 volts with all lamps turned on, steps should be taken to correct the difficulty before photographing is attempted, since serious disturbances of the color balance will otherwise result. The adjustment can be made by means of a voltage regulator or an adjustable transformer such as a Variac. In measuring the voltage, the meter used should be a rugged long-scale instrument (7 inches or so) with accuracy guaranteed by the manufacturer in the order of 2%. The full-scale

reading of the voltmeter should not be greater than the voltage at which the instrument is used by more than 15% if the usual advantages of meter-scale accuracy are to be realized.

Exposure Time and Camera Speed

It must be recognized at the outset that control of exposure time in a 16-mm camera operating at the nominal sound speed of 24 frames per second cannot be maintained accurately without suitable power drive. As of the time of writing, the only suitable power drives commercially available are two types of electric motor: (*1*) an alternating current synchronous motor energized from a central station line or other line of good frequency regulation and (*2*) a governor-controlled, direct-current motor of the Lee governor type. Good central station frequency regulation is usually better than 0.5%. Good governor-controlled, direct-current motors are guaranteed for 1% and can maintain 0.5 to 0.75% with properly designed associated equipment.

There has been no camera marketed so far with other than electric drive that is capable of propelling as little as 30 feet of film at 24 frames per second $\pm 1\%$. Since the mechanical load presented by a camera to a motor or other source of driving force varies over rather wide limits, especially when the ambient temperature changes, any form of drive other than electric may be subject to suspicion when accurate exposure control is desired. In the case of motor drive, a suitable manufacturer's guarantee of speed regulation should be a prerequisite to purchase. Admittedly, it is not simple to maintain a speed tolerance of 0.5% but it may be accomplished with an adequately large synchronous motor energized from the alternating-current mains. Unfortunately, there are many situations in which the recommended camera speed deviation cannot be maintained even with an adequate synchronous motor energized from an adequate central station mains supply. This would occur in certain cases of operation at low temperatures.

A camera should be expected to function consistently and properly under the worst combination of adverse circumstances found in practice. A safety factor of 1.5–2 to 1 in torque required should be considered essential for the worst condition to be encountered with the largest roll of film placed in the camera, and the lowest temperature under which the equipment will function. Should the camera fail to come up to speed properly, it is quite likely that an improper grade of camera oil was used. Unless special oils are used for camera lubrication, the increased

mechanical load at low temperatures becomes so great due to oil "stiffening" that it is not possible to find a suitable motor to run the camera. It would be undesirable to try to run the camera under such conditions, since delicate parts would probably be ruined by improper lubrication. Suitable camera oils are generically quite similar to the aircraft instrument oils supplied by all the large oil companies in accordance with JAN specifications. Such oils are essentially acid-free, light, petroleum-base oils with added viscosity-extenders.* Most camera manufacturers supply small quantities of quite similar oils under their private brand names—at very high prices. Unfortunately, the catalog descriptions of such lubricants are vague and provide no engineering information whatever: it is usually said or implied that the oil supplied is simply wonderful for any camera bearing the same brand name. Despite this undesirable trade practice, such branded oils are usually infinitely better than any of the ordinary automobile engine oils sold at gas stations and are still better than the "miscellaneous" oils (such as "3-in-1") that are sold so widely for use in the home. Automobile engine oils should be especially avoided because of unfavorable viscosity–temperature characteristics, and miscellaneous oils should be avoided because of a tendency to "gum" unfavorable viscosity–temperature characteristics, doubtful lubricating powers, high acid content, or for one or more of a combination of measurable characteristics that can be quantitatively evaluated in accordance with ASTM and other standard test procedures.

One suitable camera oil of the general class described is Esso Aviation Instrument Oil WS–429 made by the Standard Oil Company of New Jersey. There are numerous similar products available from other major oil refining companies.

Lenses and Lens Aperture Markings

When the photographer sets the iris diaphragm of the lens on his camera, often he does not realize that the lens manufacturer's "f/"†

* Many viscosity extenders are organic compounds that are subject to bacterial and fungal attack under tropical conditions of use.

† According to ASA Z38.4.7–1943:

1. The symbol for relative aperture of a lens shall be *f*/ followed by the numerical value of the quotient of the focal length divided by the effective aperture, as in the example *f*/8. Where preferable, the symbol *f*: may be used.

2. The measured diameter of the maximum aperture, as seen from the front of the lens, shall be at least 95% of the quotient obtained on dividing the engraved focal length by the engraved *f*-number.

3. The standard series of diaphragm markings shall be *f*/0.7, 1.0, 1.4, 2.0, 2.8, 4.0, 5.6, 8, 11, 16, 22, 32, 45, 64, 90, 128.

(*Footnote continued on p. 78.*)

(relative aperture) stop markings are not actual light transmission markings at all, but are merely markings derived from calculations related to the theoretical light transmission geometry of the lens. Such markings ignore entirely the losses due to absorption, reflection, refraction, and the like that always occur when a light ray passes from one medium to another.

The actual transmission (*t*) of a lens is always less than its relative aperture (*f/*) rating. Since a loss of 2% to 5% can always be expected for each surface traversed by a light ray, it is apparent that the transmission loss of a lens which may be thought of as the per cent difference between the "*t*" and the "*f/*" depends upon two factors: (*1*) the light loss at each surface—which depends upon the design and the coating (if any), and (*2*) the number of surfaces involved. Since in lenses of long focal length, such as the two-element Petzval design in which the number of elements is small and the design is good, the transmission loss may be even less than 10%. In a multi-element design, such as the Tessar which is one of the finest designs ever produced, the transmission loss for an uncoated lens will ordinarily be about 25%. If that good Tessar lens is coated, the transmission loss at each surface may be reduced to one-half of its uncoated transmission loss. It is unfortunate that a relatively large number of lens elements is necessary for lenses of short focal length and of wide aperture if proper color correction and good field flatness are to be achieved. It is obvious that the increase in transmission of a multi-element lens such as a Tessar is much greater than the increase in transmission of a Petzval-type lens when such lenses are coated. Lens coating is especially desirable in both cases despite the relatively small improvement in transmission in the case of the Petzval-type lens. In both cases there is a material increase in lens definition ("crispness") that in itself is very desirable. Strange as it may seem, the improvement in definition is appreciably greater for a lens of good design than for one of poor design. Lenses of poor design show improvement primarily in transmission—still less improvement in definition.

It will be found that a good 102-mm Eastman coated lens of *f*/2.7 rating will show greater light transmission than a good 1-inch Taylor-

4. The maximum relative aperture marked on a lens need not be selected from the above series but should be followed by the above series of stop openings beginning with the next larger number whenever practical and progressing as far as required in the individual application. Example: An *f*/1.9 lens might be engraved *f*/1.9, 2.8, 4 5.6, 8, etc., if it were felt that to mark it *f*/1.9, 2.0, 2.8, 4.0, 5.6, etc., would confuse the markings at the *f*/1.9 end of the scale.

Hobson-Cooke uncoated lens of $f/1.8$ rating when both lenses are set for $f/2.8$ aperture. If the latter lens would be coated, its transmission loss would be reduced. Because of the relatively large number of elements used in its design, it will still show lower transmission at the $f/2.8$ marking than the 102-mm Eastman lens even though the coating is equally good on both lenses. Incidentally, the calibration of most photoelectric exposure meters assumes the arbitrary value of 76% for lens transmission.

It is only within very recent years that the interest in measuring lens transmission has reached the point where the methods of making such measurements in a truly scientific manner have been evolved and used outside the research laboratory. What is more appropriate for the individual photographer than scientific transmission measurement as such is to have at hand a precalibrated reference lens with which other lenses that he uses may be compared. This reference lens is used as a secondary standard for rating all other lenses; it should be measured for transmission by a reputable testing laboratory (*e.g.*, the Electrical Testing Laboratories of New York).* Since the Eastman 102-mm $f/2.7$ lens is well constructed and has clearly marked f/stop engraved lines, and is a simple coated lens of good design, it can be recommended for this purpose. Since a 102-mm lens is needed but occasionally in ordinary photographing, it can be used for comparison calibrations when not actually needed for photographing.

Many arrangements can be suggested for making "f"† measurements and for making comparison calibrations. All require the following:

(*1*) A light source.

(*2*) A lens mount with suitable detecting apparatus. This may consist of a photoelectric cell or cells that are stable (relatively unaffected by temperature, aging, or other uncontrolled variation).

(*3*) An indicating meter. This may be a microammeter that is stable.

The actual exposure of film is not used in making a "t" calibration since it would introduce additional unrelated variables. The apparatus should be built up ruggedly with all parts that are not moved for adjustment purposes fixed in location with respect to one another. An old

* Reputable testing laboratories are found in most large cities throughout the United States. Information concerning them can be obtained from the Society of Motion Picture Engineers and from the American Standards Association, Inc.

† The "t-number" of a lens is the f-number of a fictitious lens having 100% transmittance and a circular aperture, which would give the same central-image illumination as the actual lens at the specified opening.

lathe bed makes an excellent foundation for this kind of apparatus just as it does in similar applications such as title and effects cameras. Such a rugged base avoids shifting of the parts with respect to the optical axis due to vibration and similar causes.

In the calibration scale, $f/4.0$ is a convenient center reference. A reasonably practical and complete scale would include a series of calibrating points from $f/0.7$ to $f/128$ in steps of one light stop—a light stop representing an area ratio of 2 to 1. Since the f/stop is numerically equal to the focal length of the lens measured in inches or millimeters divided by the diameter of the iris or other diaphragm opening, the series of light step calibrations will include the following: 0.7, 1.0, 1.4, 2.0, 2.8, 4.0, 5.6, 8., 11., 16., 22., 32., 45., 64., 90., 128.

These calibration points are specified as the standard series of markings in the American Standard Z38.4.7–1943 in item 3 of *American Standard Lens Aperture Markings.*

A serious practical difficulty encountered in setting exposure correctly with many lenses is the confused and inaccurate manner in which the index markings are made on the lens. Some time ago it was the general practice of manufacturers to mark the f/stop numbers and their corresponding index lines on the periphery of the small iris adjusting ring of the lens. Since the iris adjusting ring of the lens is small and the number of points to be marked is quite large, the manufacturer was faced with the choice of making his markings and index lines too small to be legible or to make them larger and too crowded and confused. The first big step in correcting this difficulty was taken in American Standard Z38.4.7–1943 when the standard series of diaphragm markings was approved. Still other improvements in marking have been suggested and tried and further standards will no doubt be promulgated when the matter has been studied more thoroughly.

For the calibration of lens transmission a rigid mounting is usually needed for the lens to be tested so that the conditions will be similar mechanically to the camera mount on which it will be used. It must be recognized that interchangeability of lenses on a camera can be accomplished only when dimensions of the lens mounting and of the cooperating mounting hole in the lens turret are made to the same basic dimension of the distance from the registration shoulder of the lens to the surface of the image plane—0.690 in. The dimensions are shown in ASA Z52.50/474–1944* for the conventional Type "C" lens mount (which is

* A revision is under way in ASA Z22 committee as Z22.76.

the trade name for the camera lens of 1.000-in. major diameter of mounting thread). That standard specifies that ". . . all registration distances shall be measured from the lens seat to the center of the picture aperture in the film plane." As will be pointed out later, errors in registration distance of 0.002 to 0.007 in. are quite common; since the error is usually made in the "full" direction, it may be corrected by milling off the appropriate amount of metal from the lens shoulder.

Back* has suggested a relatively simple arrangement that can be constructed by a person with some training in physics. This apparatus, which checks absolute transmission, is an embodiment of the concepts of Berlant, Gardner, and others. If the reference apparatus is too costly or too complicated for the individual photographer, it is possible to have a reference lens measured at a commercial testing laboratory on some apparatus like that which Back suggested, and to make comparisons among the lenses at hand using the tested lens as a reference. Such organizations as Electrical Testing Laboratories have the necessary "know-how," and the charges for their services are very small indeed in terms of the services rendered.

Exposure Tests

When using lenses for making comparative exposure tests, the identical group of lens *f/* stop and focus settings should be used in all cases. These should be carefully and accurately set to clearly defined markings in the recommended series of values. If such markings do not exist, it will pay to have them engraved. The lens should be returned to its manufacturer for this work.

The Film

Last but not least in importance is the film itself. As pointed out in Chapter 2, no two lots of manufactured film are sufficiently alike to permit indiscriminate interchangeability in use. As a practical matter, the variations in base characteristics are usually of little importance; it is the variations of sensitometric characteristics that require attention.

A convenient starting point is to provide sufficient film of the same emulsion-lot number for the complete production picture. Obviously, in an estimate of the film required, due allowance must be made for retakes and exposure tests. Every manufacturer of motion-picture film keeps complete and accurate data concerning the sensitometric charac-

* *JSMPE,* 49. (Aug. 1947)—several papers including that of Back.

teristics of each lot of film manufactured. This data is often utilized when an appreciable quantity of film arrives at the manufacturer's processing laboratory in a single batch for processing; this is done to minimize picture quality variations due to the film and its development.

Before production is begun, a test scene should be photographed to check the reading of the exposure meter against the exposure actually obtained. In photographing the test scene, several exposures are made in sequence; each is sufficiently long (a few feet) to make certain that the camera is operating at correct speed. A typical series of exposures would be:

Take 1: 1 stop overexposed.
Take 2: 1/2 stop overexposed.
Take 3: Correct exposure.
Take 4: 1/2 stop underexposed.
Take 5: 1 stop underexposed.
Take 6: 1 1/2 stops underexposed.

This complete test should be made with the lens to be most frequently used. A shorter test with only takes 1, 3, and 5 can be made on each of the other lenses that will be used if it is felt that the saving of time justifies this shortened procedure; the longer test is preferable.

It should be possible to duplicate the test exposure at any desired time; a test chart is therefore a convenient subject.* Exposure may be measured with an exposure meter and checked with a Macbeth Illuminometer.† When the exposed test film is ready to be shipped to the laboratory, a log sheet describing the test should be taped to the outside of the sealed film can in which the film is packed. In addition to the log sheet there should be suitable instructions such as:

''This is a picture exposure test on Kodachrome 5264 emulsion lot #982 per log sheet herewith. Please develop at standard time. View these tests and advise which take most closely approximates correct exposure for duplicating. This test will be used as the basis for the exposure of (6000) ft. of film of the same lot number. Please return this test with the log and your comments.''

For convenience in record keeping, only a single roll of exposed film should be packed in a can. Each can sent to a laboratory should

* For convenience in measuring, two subjects should be photographed for each exposure; one, a test chart, the second, a grey card of the same size made of the same material as that used for taking reflection exposure readings with the exposure meter. The grey frame may readily be measured for density with a densitometer, thereby permitting calibration of the exposures actually obtained.

† Manufactured by Leeds and Northrup, Philadelphia, Pa.

be identified by a can number; it is desirable to serially number the cans for each particular manufacturer's laboratory.

Because of the high order of accuracy in developing control exercised, it is recommended that the initial exposure tests be made with Kodachrome that is shipped to Eastman Kodak for processing. It is suggested also that about 5 feet of unexposed film be left on the outside of the test roll; in the developing instructions accompanying the log sheet it is desirable to request that the unexposed film be exposed with a IIB sensitometer strip and other suitable standardized exposures.

When the test is returned from Kodak, the projection of the test will indicate whether the lens *f*/stop markings are seriously in error and what setting corrections should be made. This exposure test supplements the lens transmission test previously described and should confirm the findings of the transmission test. In general, the production exposure chosen should be $\frac{1}{2}$ light stop underexposed as determined by these tests. (It is better to underexpose than to overexpose; if in doubt —underexpose.)

If the laboratory is located some distance from location, it is usually good practice to ship exposure tests to the laboratory some two weeks before production shooting is scheduled to begin. A time interval is usually necessary to check and correct minor difficulties that might otherwise arise unnoticed. Should doubt ever arise concerning the control of exposure, it is usually best to make a complete new series of tests.

Since the shooting of the picture may extend over a month or more, a schedule for developing the exposed film should be arranged with the film manufacturer's laboratory. Although it is customarily good practice to develop film within 24 hours of exposure, in the case of color film it is actually preferable to accumulate all the film exposed during a week, for example, or for the duration of all shooting, and to ship it to the laboratory for developing in a single lot. This procedure is especially advantageous for developing Kodachrome or AnscoColor because a shift in color balance from one day to another does occur in developing, while the drift in color balance that occurs during a single day is much smaller. To make such a scheduling procedure workable requires suitable cooled storage for the accumulated film and identification of the cans for the date of exposure. To get the most from the arrangement, the developing instructions accompanying the film should refer to the laboratory identification number and the date that the reference test was developed.

It is presumed that film will be placed in a can and sealed with Kodatape or other sealing tape shortly after exposure. In the event that only a portion of a roll has been exposed at the time a day's shooting is ended, the exposed portion will be placed in a sealed can and set aside for processing. The word "EXPOSED" and the length of the piece should be marked on the log sheet taped to the can. The unexposed remainder of the roll should be placed in an identified sealed can and remain there until needed for shooting.

In storing film, rapid changes in temperature should be avoided. General notes on storage and preservation will be found in chapter XI.

The 16-Mm Sound Original

Historical Background

In recent years most attention has been concentrated upon variable-area sound recording for 16-mm films; few 16-mm variable-density recording machines of commercial reliability have been manufactured and used. Most variable-density sound tracks that appear on 16-mm release prints in the United States are made by optical reduction from 35-mm variable-density negatives.

To obtain consistent and satisfactory 16-mm sound on release prints requires good laboratory processing control regardless of the method of recording used. Since most laboratories handling 16-mm film originally considered 16-mm processing merely as a sideline in connection with their 35-mm business, the competitive practices common in 35-mm processing were merely carried over to 16-mm in aggravated form. In extreme cases, where the Government considered low price the most important factor in awarding certain processing contrasts in World War II, some release prints were made that were of doubtful value. The lack of projector standardization was a further handicap; the fact that a sound track was intelligible on one projector did not assure its intelligibility on any other. The situation became so acute that quality improvement and standardization was the basic assignment of the Z52 War Committee on Photography and Cinematography of the American Standards Association.

The lead in the solution of these problems was taken, to a considerable extent, by manufacturers and film producers (together with their associated film processing laboratories), whose primary business was direct 16-mm. Since these groups had for some time been marketing prints made almost entirely from 16-mm originals, the integration of

equipment characteristics with production and laboratory procedures had been a pressing problem. It was fortunate that this reservoir of knowledge and experience in coordination was available because it played an important role in the rapid formulation and adoption of a large number of war standards. It is also interesting to note that before World War II, the larger sound equipment manufacturers such as RCA and Western Electric—who had been responsible for many advances in 35-mm recording—did not take an active part in the intensive development of 16-mm recording.

When 16-mm sound-recording equipment was first manufactured, the quality of release prints made from originals produced by such equipment was so inconsistent and unreliable that it proved a serious handicap to equipment sales. There was one obvious solution: technological control of laboratory processing operations as an integral part of film production operations. This could only be accomplished by having processing laboratories and equipment manufacturers combining forces. In effect, the manufacturer of 16-mm equipment was required to guarantee not only the performance of the production equipment itself, but also the end product resulting from its operation. It was under such conditions that variable-area sound recording came into widespread use in direct 16-mm almost to the exclusion of variable density.

Present Status of 16-Mm Variable-Area Sound

Since 16-mm film has a linear speed of only 36 feet per minute as compared with 90 feet per minute for 35-mm every precaution must be observed to maintain the maximum resolving power practicable in order to provide release prints of satisfactory quality. Conventional 35-mm ordinary positive film emulsions show inferior resolving power; an increase in resolving power in the ratio of the linear film speeds (90/36) is necessary to maintain comparable performance.

The first film on the market that approached this design objective was Agfa 250 (later known as Ansco 2250).* This is a film with a yellow-dyed emulsion of appreciably higher resolving power than the ordinary positive previously used; it is coated on a clear base. To take maximum advantage of the emulsion sensitizing, a blue filter (Jena BG-12), is used in the light beam of the optical system of the recording machine. This film was suitable not only for sound negatives but also for sound prints

* This film has since been discontinued as a stock item.

and for direct positives. The distortion resulting from image spread and similar undesirable photographic characteristics is quite small compared to conventional printing positive materials, and the resolving power is appreciably greater. Although there are emulsion types that have greater resolving power (*e.g.*, panchromatic microcopy), there are none that have sufficient photographic speed and other required characteristics to make them suitable for variable-area 16-mm sound recording with either existing recording machines or with machines likely to be designed and manufactured in the near future.

A more recent material designed for the same purpose is Eastman Code 5372, introduced in 1943. This film is coated on an anti-halation blue-dyed safety base of the sort commonly used for the universal types of 16-mm reversal picture films. Since it is the emulsion density that is important in sensitometric control, all measurements of sound track density must take into account the density of the base (0.26) by adding this density to the emulsion density to obtain the total density of the dark area of the sound track as measured by an Eastman densitometer. The emulsion density found desirable for Eastman 5372 is of the same order as that for Ansco 2250.

After the initial ''bugs'' had been ironed out during the early stages of its marketing in the 16-mm width on safety base, this excellent Eastman material was offered for sale in the 35-mm width. Its use is increasing rapidly in 35-mm quite as it did in 16-mm.

The 16-mm product is now under excellent manufacturing control and represents probably the finest film ever offered on the market for 16-mm variable-area sound uses. It has been manufactured for some time on a low-shrinkage safety base; the combination of excellent physical and sensitometric characteristics together with good aging properties make it an outstanding product. It may be used as:

(*1*) Sound negative for recording and re-recording.
(*2*) Sound direct positive for recording and re-recording.
(*3*) Sound printing positive.

It can be recommended for all film uses where the blue-dyed base is not a disadvantage. The manufacturer has coated the same emulsion upon a clear safety base for sound uses where the dyed base would be a disadvantage; the test films supplied by the Society of Motion Picture Engineers were produced on this film which was guaranteed to have a shrinkage of 0.5% or less.*

* In accordance with the War Standard test for shrinkage as described in Ap-

Up to the present time, most 16-mm variable-area originals have been recorded and developed as negatives. The instructions for the standardization of sound exposure for such originals, recorded with a Maurer sound recorder using a 2 ampere lamp, are given in the section following. The instructions for exposing and standardizing direct positives made with equipment of similar manufacture are similar except for the emulsion density recommendations; a density of approximately 1.5 is used instead of one of 1.9. Further data is given later in this chapter.

Standardization of Exposure for Sound Recording

Production Test Exposure

In the recording of variable area sound on 16-mm film, both accurately controlled exposure and accurately controlled development are essential for consistent high-quality results. With coordinated control of both, the sound quality regularly obtained should be substantially equal to that found in neighborhood entertainment theatres which use 35-mm film.

Experience indicates that sound should be recorded only upon high-resolving-power film (such as Kodak 5372) exposed through a blue filter (such as the Jena BG-12). All recent Maurer sound recorders have a suitable filter installed; maximum resolving power consistent with adequate exposure is ordinarily obtained with the arrangement specified by the manufacturer. Experience also indicates that for the best sound negative the density of the exposed portion of the film should be approximately 1.9 at standard development time. Proper exposure is, therefore, that which provides a density of 1.9 at standard development time. The density referred to is the emulsion density, and does not include the density of the nonhalation tinted base. Thus, the density read upon Ansco 2250 would be 1.9, since the base of the film is clear; the density read upon Kodak 5372 film is 1.9 plus 0.26 (the average density reading for the blue-tinted base), which equals 2.16.

No two lamps, no two recording optical systems, or no two emulsion lots of the same kind of film are identical in speed. The general method of control is to calibrate each lamp, optical system, or emulsion lot of film in terms of a reference lamp calibration difference current. These

pendix V and other appendices of Joint Army-Navy Specification JAN–P–49 dated 31 May 1944. (An equivalent specification was issued by the American Standards Association.)

calibration difference currents are determined by test *before* placing the new lamp, machine, or lot number of film in service for production.

The density, or blackness, of sound tracks is usually measured on an Eastman 2A densitometer* or other suitable densitometer described in the earlier chapter on film. Although most film processing laboratories can be relied on to read sound-track densities properly when requested, it is good practice for the sound recordist to get into the habit of regularly checking the sound negatives that he exposes.

The Eastman densitometer requires a uniformly exposed circular area on the sound track of at least 0.035-in. diameter, and should preferably be even larger. An exposure test suited for checking with this densitometer should appear on the end of *every* roll of sound film recorded. Since the width of an unbiased sound track is only one-half the full track width of 0.060 in., a test without bias is unsatisfactory in that it produces a track width less than the minimum required. Bias should therefore be applied to the galvanometer so that the exposed width exceeds the required 0.035 in. This can be conveniently accomplished, when, at the end of the last "take" on a roll, the "mic" and other signal imput keys are turned off, and the bias key is switched from "decrease" to "increase." In this interval the exposure lamp current remains unchanged and should be read. After 7 to 10 feet of film have passed through the machine with the bias key in the reverse position, the motor switch may be snapped off. This test will provide an exposed width of 0.055 in. or more.

A bound notebook used as a log book is essential for keeping complete, accurate, and regular records of all film exposed. With a log book conscientiously kept, it has been possible to obtain excellent coordination between laboratory and equipment user. With such cooperation and forethought, emergency telephone and telegraph messages can be virtually eliminated, and all necessary information can be conveyed with complete understanding in either direction without the need for verbal instructions.

Initial Standardization of Exposure: Lamp Standardization

In order to make the method of calibration practicable, it is necessary to reduce all calibration differences to a common denominator. The simplest and most suitable is lamp current. The first step is to keep all other factors constant (e.g., film, recording machine, and processing

* Made by the Eastman Kodak Company of Rochester, N.Y.

bath) while standardizing the exposure lamps. In the discussion that follows, it is assumed that the exposure lamp used has a nominal rating of 8 volts–2 amperes; the envelope of this lamp is tubular. These lamps as supplied by Maurer* are prefocused and require no special adjustment to align them properly in the optical system of the sound-recording machine.

The materials on hand must be properly checked and identified. In the average case, this implies a stock of 6 recording lamps and a month's supply of raw film *all of the identical emulsion lot number.* The lamps should be numbered consecutively (beginning with #1) by scratching the number with a scriber on the prefocus base of each lamp to be identified. The label of each can or carton of raw film should be stamped with the date of receipt from the film supplier. A permanent record of this and other relevant exposure data may be kept in an exposure data log book.

Recording the Exposure Test

(1) With all switches ''OFF,'' insert lamp #1 in the recording machine. Seat the lamp properly in the socket by turning it firmly into position to make certain that the filament is in the proper location. (Use the lamp originally installed in the machine as lamp #1.)

(*2*) Thread the film in the recording machine. With all input switches (''mic'' and ''non-sync'') ''OFF,'' turn off the AGN (bias) amplifier. Turn on the power supply. Make up a log sheet. Specify the emulsion lot number of the film.

(*a*) Record 5 feet of film at 1.95 amps. Enter on log sheet.

(*b*) Record 5 feet of film at 2.00 amps. Enter on log sheet.

(*c*) Record 5 feet at 2.05 amps. In the middle of this recording, snap the bias key back and forth quickly once. Enter on log sheet.

(*d*) Record 5 feet at 2.10 amps. Enter on log sheet.

(*e*) Record 5 feet at 2.15 amps. Enter on log sheet.

(*3*) Turn off the power at the power supply. Open the recorder door momentarily—fogging the film for identification. Enter on log sheet. Remove lamp #1 and insert lamp #2 into the socket.

Record 5 feet at 2.00 amps. During this recording, snap the bias key back and forth *twice* to identify this test for lamp #2. At the end of the recording, open the recorder door momentarily. Enter on log sheet.

(*4*) Repeat the procedure in (*3*) for each additional lamp, snapping the bias key back and forth quickly for the number of times required to identify the particular lamp. Make the proper entries on the log sheet.

(*5*) Complete the log sheet. Make a note on the log sheet for the developing laboratory: ''Please read the densities of the exposures indicated and note these beside

---

* J. A. Maurer, Inc., Long Island City, New York.

the exposures indicated. Develop standard time (6 minutes)*, return original log sheet, retain carbon copy in the Laboratory file.''

If the lamp originally installed in the machine was burned out prior to this test, it is advisable to follow the recording procedure of section (*2*) above for at least two lamps.

Send the film to the laboratory with the original and first carbon copy of the log sheet taped across the film can. Mark the folded sheets ''Exposure Test.'' Retain the second carbon copy. In sending written instructions to a laboratory, it is good practice to make them so clear, concise, and complete that the laboratory man can follow the written instructions with no other knowledge of the conditions under which the films were exposed.

Developing the Exposure Test

Upon receipt of the exposure test film, the laboratory, following your instructions, develops it at the standard time* of 6 minutes. After development, the film is turnd over to the laboratory control department where the log sheets and instructions are checked against the film and the necessary density measurements made. The data is then entered on the original log sheet for return to you; the film is ordinarily not returned unless you ask for it, since it is of no further value. The carbon copy of the log sheet may be retained in the laboratory technical file for future reference in connection with your work.

Plotting the Results of the Exposure Test

From the densities marked on the log sheet for lamp #1, prepare a curve sheet of lamp current *vs.* density as per Figure 4; the scale shown is the smallest that should be used.

Plot the points for lamp #1 first; the plotted points should form a straight line. Draw the straight line with a ruler. The point at which this diagonal line intersects the 1.90 density line is the *Reference Lamp Calibration Current* for the emulsion number and the lot number of the film used. Place a piece of white adhesive tape across the left half of the black case of the lamp ammeter located on the amplifier (just below the meter scale); mark this current reading on the tape together with the word ''REFERENCE'' and the emulsion and lot number of the film used.

On the same curve sheet, plot the point for lamp #2. Through this

* ''Standard'' development time will have a different value for each developer in each laboratory.

point draw a straight line parallel to the diagonal line for lamp #1. This new line will intersect the 1.90 density line at the correct lamp current for lamp #2; the difference between this current and the Reference Lamp Calibration Current is the *Lamp Difference Current* for lamp #2. On a piece of tape of similar size to that previously attached to the ammeter, mark the words: "LAMP #2–ADD (or SUBTRACT) 0—AMP"; the lamp difference current. Attach this tape to the base of the lamp concerned. Repeat this procedure for each lamp, being certain

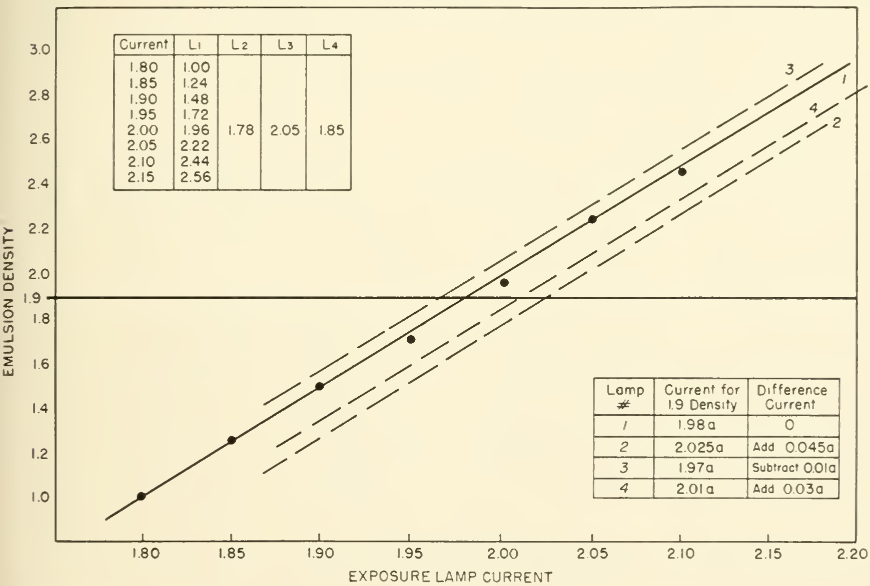


Fig. 4. Characteristic curves obtained by plotting density vs. currents for four recording exposure lamps on Eastman 5372 sound recording positive film exposed in a Maurer sound recording machine. The film was developed 6 minutes ("standard" time) at "standard" temperature (68 F) in a concentrated Eastman D-16 type bath. *Note 1:* Add 0.28 to the emulsion density shown on the curve to obtain total density as customarily reported by laboratories. *Note 2:* For blue-base stock such as EK 5372, add 0.28 to emulsion density for total density.

to number each one correctly. Enter all the data in the permanent exposure log book.

The lamps are now calibrated and are ready for production recording. On a piece of tape such as described above, mark the words "LAMP #1—NO CORRECTION"; attach this tape to the ammeter beside the *Reference Lamp Calibration Current* tape. Install lamp #1;

during its life, use the *Reference Lamp Calibration Current,* since there is no correction for this lamp. Lamp #1 may be used until it burns out.

When a new lamp is to be installed, remove the old lamp from the machine and attach it to the *Lamp Difference Current* tape located on the right side of the ammeter (unless of course this is lamp #1, in which case it would be the *No Correction* tape instead); mark this tape "BO" (burned out). Remove the tape from the base of the new lamp, attaching it in place on the right side of the ammeter, and install the new lamp. When recording, use the sum of the currents marked on the two tapes now on the ammeter, and identify the new lamp on the log sheet. *Do not detach the Reference Lamp Calibration Current tape unless a completely new calibration is made.* If the test is carefully made and records kept properly, this is unnecessary.

If ammeter readings are carefully made and the system outlined studiously followed, there should be little reason for an over-all density variation of more than 0.1 from the reference of 1.9; this represents good control for this type of sound film negative.

It is good practice to check the density measurements made by the laboratory. If discrepancies are noted as a result of these measurement checks, the measuring densitometers should be calibrated to detect the source of the error. It should be remembered that the optical wedge used for measuring purposes in the Eastman wedge densitometer is a photographic wedge; it is not to be relied on over long periods without calibration. Good practice dictates that it shall be checked on the average of once a month. To make certain that calibration is done properly, refer the request for calibration to the manufacturer of the densitometer.

Standardization of Exposure of Direct Sound Positives

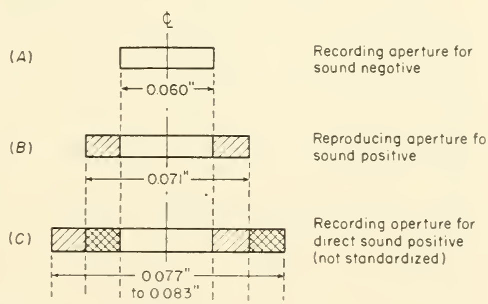
It is not practicable to attempt to record a direct sound positive with a sound-recording machine designed to record only sound negatives. While at first glance it may seem possible to record a negative image and develop the film by the reversal process, this has been found impracticable, since the distortion produced in such variable-area records is excessive.

Merely reversing the bias key on a recording machine designed for negative recording, while capable of producing a record that is not distorted, does produce a record that is excessively noisy. The reason for this becomes apparent when it is seen that the standard width of a scanning beam in a 16-mm sound projector is 0.071 in. while the standard

width of a fully modulated negative sound track is only 0.060 in. As the space on the film represented by the difference between the 0.071 in. scanning beam of the projector and the 0.060-in. sound track produced by the recording machine is transparent because it is not exposed by the recording machine designed to produce a sound negative record, this unexposed width is a very serious source of noise, because even the very small amount of dirt accumulated in very careful handling of the films causes a large modulation of the light beam through the transparent portion. This is heard as a hissing and scratchy noise from the loudspeaker when the film is reproduced.

To record a direct positive satisfactorily requires an exposure width sufficiently wider than 0.071 in. to insure that the projector scanning

Fig. 5. Dimensional relationships: (*A*) recording aperture for sound negative. (*B*) reproducing aperture, and (*C*) recording aperture for direct sound positive. *Note 1:* 100% modulation is limited to 0.060 in. regardless of aperture used. *Note 2:* All apertures are symmetrical with respect to center line. *Note 3:* All center lines are colinear. (The shaded areas represent the overlaps that allow for the mechanical guiding errors and weaves of the recording machines, the printing machines, the sound projector, and all other intermediate apparatus used.)



beam never strikes clear film outside the modulated track where there is no recorded sound. This is ordinarily assured if the width of the 16-mm, direct-positive recording aperture is 0.006 to 0.012 in. wider than the sound-scanning beam of the projector. Since good design dictates that the standard sound track center line of 0.058 in. shall be maintained in all cases, the additional width is added in equal parts to either end. Figure 5 illustrates the relationships.

Since standard sound-recording machines are designed to accommodate a modulated track width of 0.060 in., any exposed width beyond this value should represent an unmodulated "blacking-in" exposure that appears on a sound positive. The density of the "blacking-in" area should be kept as high as possible so that the track will produce minimum noise. In practice, "blacking-in" will be accomplished satisfactorily if the additional area is completely blacked-in with a uniform density equal to that of the dark portion of track area proper.

The smaller dimension of 0.077 in. may be used satisfactorily if the direct-positive sound record will be used on a film phonograph or for other purposes in which the cumulative weave and the mechanical guiding errors are of small magnitude. The larger dimension of 0.083 in. should be used when the cumulative weave and mechanical guiding errors are of larger order, as is the case if the direct positive is to be used for printing sound on a Kodachrome release print that will be projected with a conventional 16-mm sound projector.

For machines that are designed to provide a direct-positive sound track, a density of approximately 1.50 will be optimal for direct playback for EK 5372 under the same developing conditions as those of a sound negative. The exact value will depend to some extent upon the developer bath and the developing machine used; a tolerance of ± 0.10 in density for measurements in the order of 1.0 to 2.0 is practicable for consistent sound quality. The minimum distortion obtainable will also depend upon the developer bath; no reliable rule-of-thumb data can be confidently given, since the distortion can vary over a very wide range. Distortion can be checked by means of a test recording made at several test exposures; although the method is empirical, it is a good guide to the result to be expected from the cross-modulation test specified in American Standard Z22.52–1946 "Cross-Modulation Tests on Variable-Area 16-Mm Sound Picture Prints." A good test sentence is the old "chestnut": Sister Susie's sewing shirts for soldiers." Because the most serious form of distortion encountered in variable-area processing is envelope distortion, a sentence with a plethora of sibilant sounds makes a good test. The subject of distortion and distortion testing and measurement is discussed in detail in the chapter on sound recording.

The optimal density of a direct positive that is to be used for printing a Kodachrome duplicate depends upon a large number of factors that include:

(*1*) Printer contrast factor and degree of collimation of the exposing illumination.
(*2*) Color temperature and spectral quality of the exposing illumination; the illuminant may be of the continuous spectrum type or of the band spectrum type.
(*3*) Turbidity and "image spread" in the direct positive.
(*4*) Turbidity and "image spread" in the Kodachrome sound track.

Since it is believed that with certain conditions the image spread in the Kodachrome duplicate can be offset by controlled overexposure and resulting image spread in the direct positive, more widely differing density requirements exist for a direct positive that is printed on Koda-

chrome with a continuous contact printer than for Kodachrome printed with an optical printer. A total density of 2.5 to 3.0 has been found advantageous with EK 5372 printed on printers such as the Depue and the Bell and Howell Model J continuous contact types with conventional heterochromatic (white light from an incandescent lamp) illumination. With these conditions, a Kodachrome sound track has been obtained that sounds somewhat better on commercial projectors than is ordinarily obtained by printing EK 5372 of lower density (found to be optimal empirically) with an older type Maurer optical one-to-one sound printer using heterochromatic or other continuous spectrum type illumination. It must be recalled that the names Kodachrome and Ansco Color are trade names and do not represent specific products. Because of the process changes that are continually taking place in an effort to reduce cost and to improve quality, no flat and unequivocal statement concerning rule-of-thumb handling of sound on Kodachrome or on AnscoColor can be valid for any considerable period of time. This is the case because the current design criteria for good sound on color films (or other films for that matter) have never been explicitly stated by the film manufacturers. Under such conditions it must be expected that objective and subjective measurements of the quality level of sound from color prints must continue to jump about from one statistical universe to another as each manufacturing process change is introduced. While it is probable that the magnitude of the "jumps" in quality, and the consequent impracticability of correlating statistically the objective and the subjective tests, will be much smaller in the future because of the lesser dislocations of the market, improvement and "tightening-up" can be expected if the market demand for quality improvement is insistent, and if there is willingness to pay a slightly higher price for the higher quality.

Direct-Positive Exposure Test Procedure

The operating procedure for making an exposure test at the end of a roll of film that has been recorded as a direct positive is the same as that described for a negative—with but one exception: it is not necessary to shift the bias key of the recording amplifier from the "wide" track position. The exposed track width provided by unmodulated track that is recorded with bias is greater than 0.071 in. (the width of the projector aperture). Since this value is wider than the 0.035-in. minimum required for an Eastman Densitometer, it will be practicable to measure track density with this commonly available instrument. Most density

measurements in film laboratories are made with an Eastman densitometer or equivalent.

Standardization of Emulsion Speed

No two emulsion lots of even the same kind of film are of the same speed. To be effective, a control method for density must take this factor into account. When film emulsions are manufactured, it is not possible to predict with absolute accuracy just what the speed and other sensitometric characteristics of a particular mix are going to be. For this reason it is common practice among sound recordists to discuss sensitometric characteristics of films in terms of their specific applications. Thus, in the case of EK 5372, for example, the speed of a particular lot of film is said to be so many milliamperes faster or slower than the reference emulsion lot.

Check the materials on hand and identify them properly. In the average case, this means that a stock of 6 recording lamps is on hand together with the month's supply of the *new* emulsion lot number, as well as at least one full unopened can of the emulsion lot number being retired. Load the recording machine magazine with this roll of the old emulsion lot number of film. Make a recording following the procedure outline in "*Recording the Exposure Test,*" steps (*1*) and (*2*). At the conclusion of this recording turn off the power supply. Remove the exposed film from the magazine and place it in the original container. Complete the log sheet. Make a note on the log sheet: "This is an emulsion test. Please read the densities of the exposures indicated and note these beside the exposures. Develop (for direct positive—3 minutes). Return the original log sheet; retain the carbon copy for the laboratory file." Remove the unexposed film from the magazine; seal it in a can in the usual manner; and identify the can with the proper emulsion lot number and other identification so that the test may be repeated at a later date if necessary.

Do the same for a test roll of the new emulsion lot. When storing the unused part of the test roll, make certain that the identification is correct and complete. Send the films to the laboratory.

Upon return of the completed log sheets from the laboratory, plot a curve for each of the two lot numbers of film in the same manner as for two new lamps. The difference between the lamp currents at density 1.50 is the *Direct Positive Film Difference Current.* If the new film requires more current than the older one, enter in the log book: "Add film

difference current 0.-- amp.''; if the new film requires less lamp current, enter in the log book: ''Subtract direct positive film difference current 0.-- amp.''

This procedure applies only to films of the same type but of different lot numbers. Films of different types cannot be properly compared by this method, since the slopes of density-exposure curves will not be alike.

Lamp Life and Lamp Conservation

In order to obtain sufficient exposure for high-resolving-power sound-recording films such as EK 5372, it is often necessary for lamp currents of 2.25 amps. or more to be used with a 2-amp. lamp. An accompanying result of high exposure currents is short lamp life; occasional comments have been made by users of recording equipment that short life has been an annoying maintenance problem.

When an original is recorded, it is essential that the effective width of the recording light beam be exceptionally small and that the film used be of the highest resolving power practicable. In everyday language, the recording line of light that is focused on the film shall operate like a very fine pencil point that is drawing the details of the sound waves being recorded. Similarly, the film used shall be capable of clearly rendering the very fine lines which the optical system of a good sound recorder can draw. The fidelity of the recorded sound is directly dependent upon the narrowness of the line of light in the sound recorder and upon the resolving power of the sound-recording film used.

The lamp used in the new Maurer sound-recording machine is rated at 8 volts-2 amps.; it has a nominal life at this rating of over 25 hours. If the lamp is operated above 2.25 amps. it is obvious that its life is correspondingly reduced. The estimated life of the lamp may be readily calculated by a lamp engineer from the above data. Even at such short life as that encountered with 2.25 amps., a single lamp is still capable of recording several reels of film; the cost of the lamp per reel is still but a fraction of the cost of the film itself.

There is a very simple method of increasing effective lamp life: *when not actually recording, reduce the lamp current by turning the lamp rheostat to the lowest position* (*counter clockwise*). Do *not* turn the lamp completely out; burning it at reduced current causes far less shock to the filament than turning it off and on. Turning the lamp down as a matter of habit will result in a great economy of lamp life; by doing so

the lamp will burn at the high and costly recording current only when actually necessary for recording purposes.

In the new Maurer sound-recording machine that uses the 2a lamp, lamp operation is more conservative—with the result that lamp life at the customary operating current is about 5 times as great as that of the 1-amp. lamp used in the earlier Model D. Despite this large increase, it is still good operating routine to reduce the lamp current approximately 80% of rated current when not actually recording.

Sound Track Fog and Its Sources

In the prior section on exposure standardization, no mention was made of sound track fog. In variable-area films, fog is a very important factor that receives little or no attention in most cases, and far less than it deserves in others.

Fog may originate in a number of ways:

(*1*) The film may be old, defective, or of an incorrect type.

(*2*) The developer may be poor or exhausted; the film may be overdeveloped.

(*3*) Stray light may reach the film; a common source is the stray light produced in the optical system of the sound-recording machine itself.

(*1*) Films for variable-area sound recording such as Eastman 5372 are designed to provide high resolving power, high contrast, and low chemical fog. With the manufacturing control exercised today, defective film is rare when film is fresh; it is only when the material is old or has been improperly stored that excessive fog and related defects are encountered. At present, no other type of film can be recommended for 16-mm variable-area sound recording; fog and other difficulties such as low resolving power are to be expected with film other than the type mentioned.

(*2*) Developing difficulties are common. The better developing agents such as Elon (Eastman Kodak) and its commercial equivalents, such as Rhodol (DuPont) Metol (Mallinkrodt and others) and Pictol (Ansco) are expensive, the cost being several dollars per pound. It is not at all uncommon for low concentrations of these excellent developing agents to be used in commercial developers together with high concentrations of alkali activators such as sodium carbonate to effect the required developer energy. Since the cost of sodium carbonate is measured in cents per pound, one reason for the substitution is obvious. Obviously, developer baths of different compositions will produce different characteristics in the sound track.

As a rule, commercial laboratories are reluctant to disclose for publication or to their customers specific information about the developer compositions used. Most commercial developers used for 16-mm sound negatives, 16-mm direct positives, and 16-mm release prints are essentially of the Eastman D-16 variety, using both Elon and hydroquinone. The major difference from laboratory to laboratory is in the Elon content and in the concentration and balance of the developer.

Actually, exact knowledge of the constituents of a given developer is of little value in a quantitative way without complete data on the operating characteristics of the machines and full knowledge of the control methods actually used. This latter information is customarily of little interest or concern to a buyer of processing laboratory services because he cannot interpret it properly; even if he could, it is not available outside the processing laboratory organization itself. For this reason the buyer's best check upon the laboratory services that are offered is measurement of the quality of the finished product. This is best accomplished quantitatively by means of test strips handled as part of the processed film. Such strips may be measured and evaluated. Although most laboratories have had considerable experience in reading densities and taking sensitometric data based on Eastman IIB sensitometer readings, their readings of fog and their numerical evaluations of other test strip data cannot be relied upon to the same degree. Such measurements and numerical evaluations should be checked independently by the user if intended for process or other control. Checking laboratory readings as a matter of routine is good procedure, since the measuring tolerances for laboratory readings are often unknown and usually have large ratios of variation from one laboratory to another.

Incorrect film density can be expected if the exposure used in the sound recorder is not set correctly for the standard developing time of the developing machine. Developing machines often require long threading that is measured in yards of threading leader; Figure 6 is a typical commercial machine. It is obvious that if your sound film is spliced to another film going through the machine directly ahead of it (as will invariably be the case in the interest of economy of handling time and cost) both pieces of film will have the same developing time. It is not unusual for some 30 to 45 minutes to elapse between the time your sound film is attached to the head end of the developing machine and the time it emerges from the dryer at the tail end. To change developing time on a production developing machine between rolls very

often involves placing leader of approximately developing machine length between your film and the one preceding it. If both films are short, 400 ft. of film or less is developed for, say, a mile of leader going through the machine. At usual prices, no commercial laboratory can operate with such a small percentage of revenue-producing film—and remain in business. The remedy is obvious: always expose sound film correctly for the developing time agreed upon as standard between the laboratory and the user. Even though a laboratory may develop a test

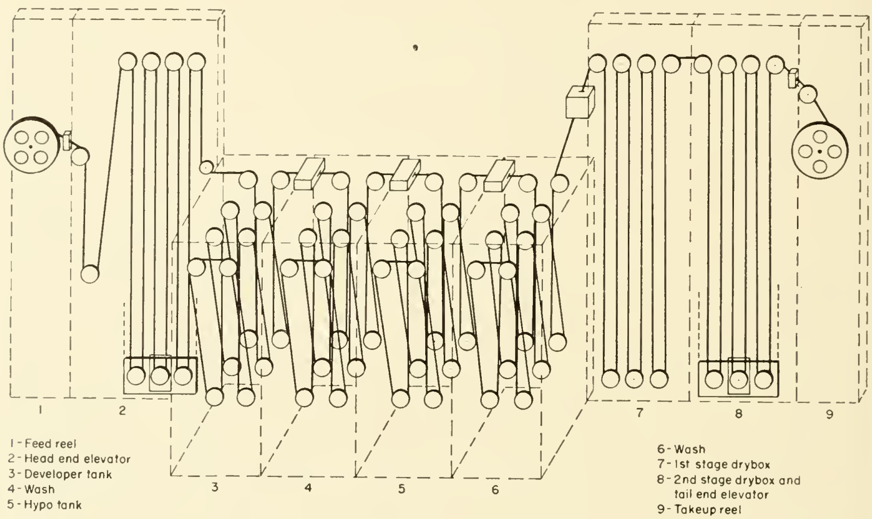


Fig. 6. A typical developing machine for positive film. The sections are: *1,* feed reel; *2,* head-end elevator; *3,* developing section; *4,* wash; *5,* hypo; *6,* wash; *7,* drybox (first section); *8,* drybox and takeup elevator; *9,* takeup reel. Protective and lubricating coatings for release prints are occasionally applied in a special section placed between sections 8 and 9.

strip before the whole film is developed, it is unreasonable to expect the laboratory to alter the developing time for your strip of film merely to correct for your carelessness in exposing the original. Incorrectly exposed originals are a disappointment to both laboratory and owner, and every effort should be made to avoid them.

In modern photographic equipment that is used intelligently, stray light is not a major source of difficulty. But there is still much room for improvement. While it is a well-known principle in optics that the number of optical surfaces through which a light beam passes should be kept to the irreducible minimum, designs for sound-recording optics are

still complex, and involve many surfaces through which light must pass from the lamp source to the film to be exposed. There is no substitute for really good optical design. Where rays are to be transmitted through an element of a system, it is still a fundamental principle to control the geometry of the system so that the spurious reflected ray is directed out of the way. This has been done well in such multi-element picture lens designs as the Tessar; the effectiveness of such excellent design is appreciated only when the performance of a coated Tessar lens is compared with that of a similarly coated lens of the same number of elements but of different design.

On the whole, the optical systems of 16-mm sound-recording machines manufactured to date have been of reasonably good design. Only within the last few years has any serious attempt been made to coat the lenses used; large and significant improvements in image contrast can be obtained by further refinement of the present basic designs and by lens coating refinements.

Significance of Sound Track Fog

From the foregoing section it is apparent that the density measured as sound track fog is different from the density measured as chemical fog. In general, sound track fog is equal to chemical fog plus the fog due to the imperfect image contrast of the optics of the sound-recording machine. The importance of maintaining low sound track fog can hardly be overestimated. Theoretically, an ideal variable-area sound track would have 100% transmission through the clear portion of the film and zero transmission through the black portion of the film. It is obvious that if we consider the output of such a sound track as 100%, the output of an actual sound track will be less than 100% because the clear portion absorbs some light and the opaque portion transmits some light.

Viewing actual sound tracks by eye is misleading because the eye responds logarithmically to light changes, whereas the reproducing photocell responds linearly. It is for this reason that a sound track that appears but slightly fogged when viewed by eye has a low output when reproduced. The loss in output of a sound track with low fog, whose opaque portion seems gray instead of black, is not as great as the loss in a dense film with high fog. The percent output of an actual sound track can be determined quickly if the density of the opaque portion and the density of the sound track fog are known. The percent output equals 100% minus the sum of the per cent output loss due to the imperfect opacity and the per cent output loss due to imperfect transmittance re-

sulting from fog, etc. The losses are readily determined from Figure 7; the output of the opaque side of the track is determined from the upper curve, and the loss due to absorption by fog from the lower.

Typical figures may be interesting as an example. In 1930 commercial sound recorders using 35-mm film turned out negatives with a

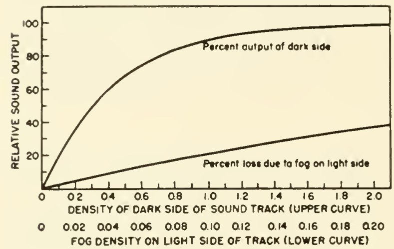
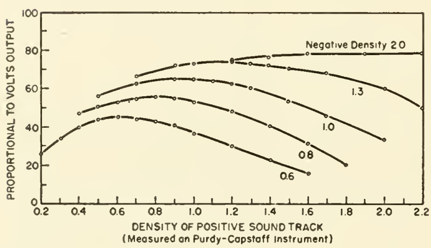
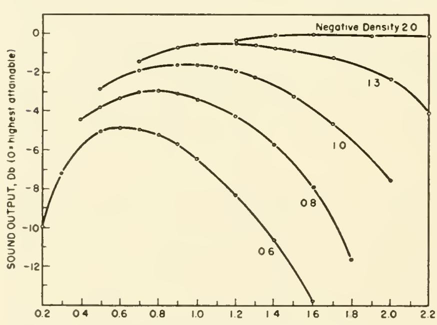


Fig. 7. Percent theoretical maximum output of variable-area sound film. Determinations made from measurements of track density (emulsion density plus fog density) and fog density. Percent output = [Percent output (from curve A)] − [percent output (from curve B)]. Track density in this case equals total density − base density.



Fog density of 0.05 assumed in clear portion. Density measured on Eastman Capstaff-Purdy densitometer; values shown are corrected for the difference between diffuse density measured with the specified densitometer, and the specular density.

Fig. 7A. Relation of print sound level output to negative and print densities.



No fog assumed for the clear portion. Density measured on Eastman Capstaff-Purdy densitometer; values shown are corrected for the difference between diffuse density measured with the specified densitometer, and the specular density. (Revised from JSMPE, June 1930, p. 640.)

Fig. 7B. Relation of print sound level to negative and print densities.

track density of 1.40 and a fog density of 0.15. The per cent of theoretical maximum output for such films was 95 − 29 = 66%. Today with good 16-mm film and processing, a track density of 1.90 with a track fog density of 0.04 is common; the per cent of theoretical maximum output for today's 16-mm film is 98 − 9 = 89%. It can be readily seen from

these figures that the major improvement has come from reducing fog, and that there is still room for appreciable further improvement in this direction.

Soon after sound films were first introduced commercially, it was quickly recognized that the sound level output of a print depended upon the density and fog of the negative, and upon the density and fog of the print. What was not as well recognized, however, was the fact that commercially available densitometers did not measure density in identical terms. The more common instruments used for control were the diffuse densitometers of which the Eastman Capstaff-Purdy was a typical example, and of which the Eastman Model 1A Densitometer is a modern counterpart. The monumental work of E. D. Cook that provided the first rigorous mathematical analysis of the aperture effect appeared in the June 1930 issue of the *Journal of the Society of Motion Picture Engineers;* it showed a disparity between the output level values calculated by Cook's method and those obtained in practice. It has taken some two decades to ascertain with reasonable certainty the sources of the disparity and to make it possible to determine the physical significance of the terms of Cook's equations. One source of difficulty is the fact that density in Cook's equations must be measured as specular density and not as some unknown density that is mostly diffuse, yet has uncertain portion of specular density involved. Figures 7A and 7B, showing the relation of sound level output of a print to the density of the negative and of the print, are revised accordingly.

Measurement of Sound Track Fog

Since some films have dyed bases and other films do not, it is usually necessary to specify just what densities are to be measured if confusion of terms is to be avoided.

A starting point in measurement is the density of the base together with the base dye (if any). This is referred to as D_{base} and can be measured merely by clearing the film emulsion (from unexposed film taken directly from a film can) with hypo and reading the cleared film with a suitable densitometer. If a base is clear, the symbol $D_{clear\ base}$ can be used; if a base is dyed, the symbol $D_{dyed\ base}$ can be used. It is not usually necessary, however, to specify whether the base is clear or dyed, since the density values will indicate this; the symbol D_b can therefore be used for base density.

Chemical fog can be determined by developing a strip of unexposed film in the manner in which regular film is developed, and then measuring

the film with a suitable densitometer. The reading thus obtained represents base density plus chemical fog density. To obtain the chemical fog density it is necessary to subtract the value of the base density previously determined. $D_{fog\ (Chem)}$ is a convenient symbol for the result.

Sound track fog arises from low exposure contrast and from chemical fog. If normal current is passed through the lamp of the sound recorder and normal bias current applied in the decrease position in order to provide the thin exposure line obtained on an unmodulated negative, the density of the unexposed portion of the sound track will be found to be higher than the chemical fog density. If such a film is developed and a densitometer reading made, the sound track fog is equal to the indicated reading minus the base density. Thus, track fog density (D_F) results from chemical fog and exposure contrast fog.

The density of the developed silver of a sound track is determined by measuring the opaque part of the film and subtracting from the value obtained the base density and the track fog density. This value obtained from a film with a dyed base (such as EK 5372) is expressed as D_{S+F+B}; the density of the track fog and the density of the base must be subtracted to provide the correct value of silver density. To the recommended silver density of 1.90 for a sound track negative, the track fog density and the base density must be added to obtain the total track density. It is total track density that is measured by commercial laboratories and reported to the customer who requests density information.

As can be appreciated after a study of the factors that affect sound track output, reliable, consistent, and periodically calibrated densitometers are necessary for good control. The Eastman Kodak densitometer, while quite reliable for measuring densities in the range of 0.4 to 2.0, is not suited to the reliable measurement of densities lower than 0.15. Other types of densitometers that are more accurate at low density values are required; suitable densitometers are the Martens polarizing-head densitometer (Ansco), the Ansco photoelectric densitometer (Ansco), and the Western Electric RA-1100 photoelectric densitometer (Electrical Research Products Division of Western Electric Company, New York City). These more accurate instruments are more costly and require careful handling comparable to that accorded a high-grade compound microscope. The Western Electric RA-1100 photoelectric densitometer is to be particularly recommended not only because of its reliability but also because readings may be made rapidly with little fatigue of the operator. The price of this instrument is over $1000.

CHAPTER V

Dimensions and Standards in 16-Mm

Introduction

The work of pioneers in any engineering field leaves behind ineradicable evidences of many of the early solutions to the various design problems encountered by these pioneers. Time usually tends to minimize the magnitude and extent of the difficulties faced by the pioneers that are taken for granted by later designers. The 16-mm motion picture is no exception in this broad generalization.

Fifty years ago at about the same time that Edison was working on the motion picture in the United States, Lumiere was working on it in France. In Lumiere's early film (35-mm in width) the sprocket hole arrangement was far simpler than that of Edison. At either side of the center of each photographed frame Lumiere provided a single circular hole by which the film was registered and propelled in the projector. Years later when 16-mm film was first made in the United States, one sprocket hole per frame was provided along each edge of the film for registration and propulsion. The significant changes of the 16-mm film compared with Lumiere's film were in the shape of the perforation (rectangular with rounded corners) and in the location of the sprocket hole (equidistant vertically between two adjacent photographed frames). The silent 16-mm film of today is made in just that manner.

Both 35-mm and 16-mm films have been formally standardized dimensionally through an international standards organization. Component groups keep the international organization continuously informed of all changes in national standards made or contemplated. Such international cooperation makes world-wide acceptance and use of motion pictures possible.

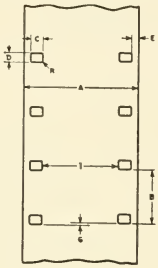
Film Dimensions

When sound was added to 16-mm film in 1930–1931 it was decided that no essential dimensional differences between cameras made for silent films and those for sound films were necessary if the sound track could be accommodated by omitting one of the two rows of sprocket holes. 16-mm sound films made throughout the world today are now made in

American Standard
Cutting and Perforating Dimensions for
16-Millimeter Silent Motion Picture
Negative and Positive Raw Stock

ASA
Reg. U. S. Pat. Off.
Z22.5-1947
Revision of
Z22.5-1941

Page 1 of 2 pages



Dimensions	Inches	Millimeters
A	0.629 ± 0.001	15.98 ± 0.03
†B*	0.3000 ± 0.0005	7.620 ± 0.013
C	0.0720 ± 0.0004	1.83 ± 0.01
D	0.0500 ± 0.0004	1.27 ± 0.01
†E	0.036 ± 0.002	0.91 ± 0.05
†G	Not > 0.001	Not > 0.025
†I	0.413 ± 0.001	10.490 ± 0.025
L‡	30.00 ± 0.03	762.00 ± 0.76
R	0.010	0.25

These dimensions and tolerances apply to the material immediately after cutting and perforating.

*In any group of four consecutive perforations, the maximum difference of pitch shall not exceed 0.001 inch and should be as much smaller as possible. (This requirement has been added to the previous standard Z22.5-1941.)

†This dimension and tolerance was given in respect to the center line of the perforations in the previous standard Z22.5-1941.

‡This dimension represents the length of any 100 consecutive perforation intervals.

Approved July 16, 1947, by the American Standards Association.
Sponsor: Society of Motion Picture Engineers.

Appendix

The dimensions given in this standard represent the practice of film manufacturers in that the dimensions and tolerances are for film immediately after perforation. The punches and dies themselves are made to tolerances considerably smaller than those given, but owing to the fact that film is a plastic material, the dimensions of the slit and perforated film never agree exactly with the dimensions of the punches and dies. Shrinkage of the fiilm, due to change in moisture content or loss of residual solvents, invariably results in a change in these dimensions during the life of the film. This change is generally uniform throughout the roll.

The uniformity of perforation is one of the most important of the variables affecting steadiness of projection.

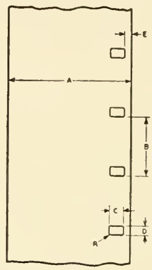
Variations in pitch from roll to roll are of little significance compared to variations from one sprocket hole to the next. Actually, it is the maximum variation from one sprocket hole to the next within any small group that is important. This is one of the reasons for the method of specifying uniformity in dimension B.

Figure 8

American Standard
Cutting and Perforating Dimensions for
16-Millimeter Sound Motion Picture
Negative and Positive Raw Stock

ASA
Reg. U. S. Pat. Off.
Z22.12-194
Revision of
Z22.12-1941

Page 1 of 2 pages



Dimensions	Inches	Millimeters
A	0.629 ± 0.001	15.98 ± 0.03
†B*	0.3000 ± 0.0005	7.620 ± 0.013
C	0.0720 ± 0.0004	1.83 ± 0.01
D	0.0500 ± 0.0004	1.27 ± 0.01
†E	0.036 ± 0.002	0.91 ± 0.05
L‡	30.00 ± 0.03	762.00 ± 0.76
R	0.010	0.25

These dimensions and tolerances apply to the material immediately after cutting and perforating.

*In any group of four consecutive perforations, the maximum difference of pitch shall not exceed 0.001 inch and should be as much smaller as possible. (This requirement has been added to the previous standard Z22.12-1941.)

†This dimension and tolerance was given in respect to the center line of the perforations in the previous standard Z22.12-1941.

‡This dimension represents the length of any 100 consecutive perforation intervals.

Approved July 16, 1947, by the American Standards Association.
Sponsor: Society of Motion Picture Engineers.

Appendix

The dimensions given in this standard represent the practice of film manufacturers in that the dimensions and tolerances are for film immediately after perforation. The punches and dies themselves are made to tolerances considerably smaller than those given, but owing to the fact that film is a plastic material, the dimensions of the slit and perforated film never agree exactly with the dimensions of the punches and dies. Shrinkage of the film, due to change in moisture content or loss of residual solvents, invariably results in a change in these dimensions during the life of the film. This change is generally uniform throughout the roll.

The uniformity of perforation is one of the most important of the variables affecting steadiness of projection.

Variations in pitch from roll to roll are of little significance compared to variations from one sprocket hole to the next. Actually, it is the maximum variation from one sprocket hole to the next within any small group that is important. This is one of the reasons for the method of specifying uniformity in dimension B.

Figure 9

that manner; only a single row of sprocket holes is used for registration and propulsion. The space formerly occupied by the second row of sprocket holes now accommodates the sound track. A camera designed for sound film propels the film by means of a single row of sprocket holes, but can accommodate either single or double-perforated silent film as well.

Figure 8 is the current American Standard Z22.5–1947 "Cutting and Perforating Dimensions for 16-Mm Silent Motion Picture Negative and Positive Raw Stock." Figure 9 is the current American Standard Z22.12–1947 "Cutting and Perforating Dimensions for 16-Mm Sound Motion Picture Negative and Positive Raw Stock." Note that all dimensions shown are identical, with the exception that the row of sprocket holes on the left side of the drawing is omitted.

Silent cameras manufactured a number of years ago often had dual claws (one on each side of the film); still other silent cameras had a single claw located on the wrong side of the film for sound motion picture film. Obviously, if single-perforated film is placed in cameras such as the latter, the sprocket teeth and other parts of the film-transport mechanism will tear the film on the sound track side. For this reason it is always wise to check a camera and its film carefully before loading. It is apparent that it is perfectly safe to thread a sound camera with silent film but it is not safe to thread a silent camera with sound film. NEVER turn on a motor switch of a camera without first turning the camera over by hand to make sure that it is properly threaded.

Basic Standards

There are several basic standards in 16-mm sound film that should be remembered by everyone concerned with 16-mm production or utilization.

(*1*) Frames per foot: 40 (Ref: ASA Z22.5 and Z22.12).

(*2*) Sound speed: 24 frames per second (Ref: ASA Z22.15 and Z22.16). The nominal equivalent is 36 feet per minute.

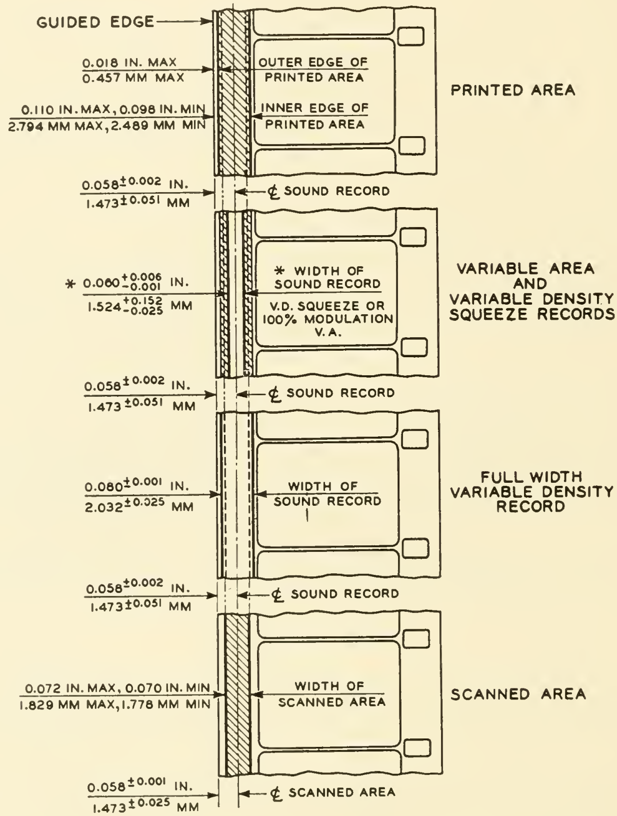
(*3*) Spacing between picture and corresponding sound: 26 frames (Ref: ASA Z22.16). This is the standard distance between the picture aperture in a 16-mm sound projector and the sound scanning beam. (Obviously this is the correct distance between picture and its corresponding sound on a release print. As the film is threaded in a projector, the sound on the film is nearer the head end of the film by the standard 26-frame interval.)

(*4*) Sound track measurement reference: all dimensions of sound track on a sound film are measured from the sound track edge (guided edge) of the film as a dimensional reference line. (See Fig. 10—ASA Z22.41.)

American Standard

Sound Records and Scanning Area
of 16-Millimeter Sound Motion Picture Prints

ASA
Reg. U. S. Pat. Off.
Z22.41-1946



These Dimensions and Locations Are Shown Relative to Unshrunk Raw Stock

*This dimension for the width of the sound record of variable density squeeze tracks and of variable area tracks at 100 percent modulation is based on present day equipment design. It is recommended that all future equipment be designed for a record width of 0.060 ± 0.001 inch. It is also recommended that existing equipment be modified to produce prints having variable density squeeze and 100 percent modulation variable area records with a width as close as practicable to 0.060 ± 0.001 inch.

Approved March 19, 1946, by the American Standards Association

Figure 10

Other Important Standards

Those concerned with actual production and editing should add some further data to the foregoing:

(*5*) Camera aperture dimensions: the standard camera aperture is 0.410 in. by 0.294 in. Best practice dictates that the aperture as photographed on the film shall be symmetrically disposed along the film with respect to the film perforations. Deviation from exact symmetry is called frame line shift; marginally acceptable practice dictates that the actual frame line shall not be out of place in either forward or rearward directions by more than 0.005 in. Good practice will show less than 0.003-in. shift; with truly professional equipment and with film in best order, a shift of one-half this amount is feasible and should be the goal.

Figure 11 is the proposed American Standard Z22.7 ''Proposed American Standard Location and Size of Picture Aperture of 16-Mm Motion Picture Cameras.'' Note that the sound and silent apertures are alike in dimensions and location; the difference is the omission of one row of sprocket holes on the sound film.

(*6*) Splice dimensions and perforation dimensions: a perforation of a 16-mm film is 0.050 in. high (nominal dimension). The straight-type splice and not the diagonal type should ordinarily be used in an original picture film. Such a splice provides a lap joint that overlaps either side of the included sprocket hole by 0.010 in. (preferred dimension). Accurate superimposition of the two overlapping sprocket holes is imperative for a good splice. Figure 12 shows the proposed standard Z22.24. A further discussion of splices will be found in Chapter X, Editing.

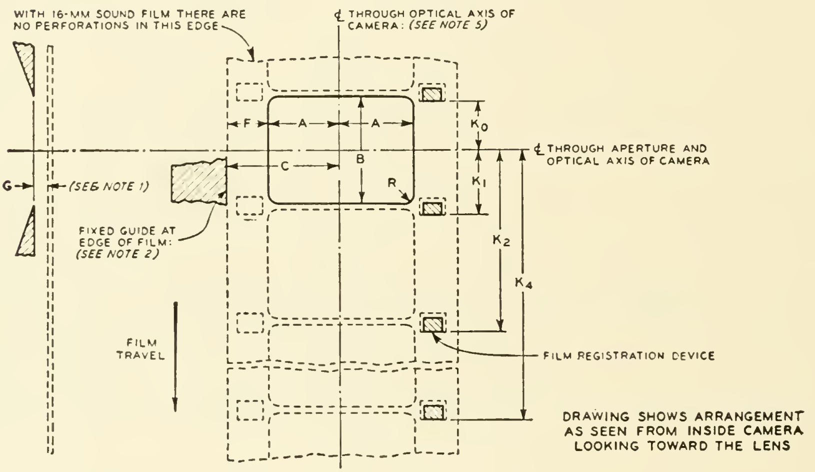
In making a splice, the emulsion is scraped from the portion to be spliced, permitting satisfactory ''welding'' of the two pieces to be joined. In all cases of professional splicing, the base of one strip of film is cemented to the scraped emulsion side of the other strip for the purpose of maintaining the same relative position of base side and emulsion side of the film in all pieces joined. Dimensions of a splice can be conveniently checked by means of a Bausch and Lomb Shop Microscope Cat #31-29-33-34.

(*7*) Projector aperture dimensions: the standard size of the projector aperture is 0.380-in. by 0.284-in. Figure 13 is Proposed American Standard Z22.8–Feb. 1949. ''Location and Size of Picture Aperture of 16-Mm. Motion Picture Projectors.'' If the dimensions of the camera aperture are compared with the dimensions of the projector aperture, it will be found that the camera aperture is appreciably larger than the projector aperture. The difference is 0.022-in. in width and 0.008-in. in height. The purpose of this dimensional difference is to allow for the various errors in placement and of weave that will occur in all machinery and films used between the original picture and the release print derived from the original. The misplacements and weaves should be comparatively small in printers and in other expensive apparatus used in film laboratories; they will be comparatively larger in projectors, since they are relatively inexpensive compared with laboratory apparatus. Under no circumstances should all the accumulated misplacements and weaves be such that an unsatisfactory picture is produced when the release print is projected through a standard projector aperture. Good practice dictates a minimum of misplacements and weaves.

(*8*) Sound track center line: the standard reference center line—used for all measurements and calculations—is 0.058 in. from the guided edge of the film. This is true for sound recorder, sound projector, sound printer, and all other sound apparatus. (Ref: ASA Z22.41.)

Proposed American Standard Location and Size of Picture Aperture of **16-Millimeter Motion Picture Cameras**	**Z22.7-** **February 1949**

This standard applies to both silent and sound 16-mm. motion picture cameras. It covers the size and shape of the picture aperture and the relative positions of the aperture, the optical axis, the edge guide, and the film registration device. The notes are a part of this standard.



Dimension	Inches	Millimeters	Note
A (measured perpendicular to edge of film)	0.201 minimum	5.11 minimum	1
B (measured parallel to edge of film)	$0.292 {+0.006 \atop -0.002}$	$7.42 {+0.18 \atop -0.05}$	1
C	0.314 ± 0.002	7.98 ± 0.05	2
F	0.110 minimum	2.79 minimum	3
K_0	0.125 ± 0.002	3.18 ± 0.05	4
K_1	0.175 ± 0.002	4.44 ± 0.05	4
K_2	0.474 ± 0.002	12.04 ± 0.05	4
K_3	0.773 ± 0.002	19.63 ± 0.05	4
K_4	1.072 ± 0.001	27.23 ± 0.03	4
R	0.020 maximum	0.51 maximum	1

Figure 11

Proposed American Standard
Location and Size of Picture Aperture of

16-Millimeter Motion Picture Cameras

Z22.7-
February 1949

The angle between the vertical edges of the aperture and the edges of normally positioned film shall be 0 degrees, ± ½ degree.

The angle between the horizontal edges of the aperture and the edges of normally positioned film shall be 90 degrees, ± ½ degree.

Note 1: Dimensions A, B, and R apply to the size of the image at the plane of the emulsion; the actual picture aperture has to be slightly smaller. The exact amount of this difference depends on the lens used and on the separation (dimension G) of the emulsion and the physical aperture. G should be no larger than is necessary to preclude scratching of the film. The greatest difference between the image size and aperture size occurs with short focal-length, large diameter lenses.

Dimensions A and B are consistent with the size of the images on a 16-mm. reduction print made from a 35-mm. negative with the standard 2.15 reduction ratio.

It is desirable to hold the vertical height of the actual aperture to a value that will insure a real (unexposed) frameline. This results in less distraction when the frameline is projected on the screen than is the case when adjacent frames overlap.

Note 2: The edge guide is shown on the sound-track edge. This location for it has the advantage that the rails bearing on the face of the film along this edge and also between the sound track and picture area can be of adequate width. Disadvantages of this location for the edge guide are that, because film shrinkage and tolerances affect the lateral position of the perforations, the pulldown tooth must be comparatively narrow and will not always be centered in the perforation.

The guide can be on the other edge, adjacent to the perforated edge of sound film. With the guide at this edge, the width of the pulldown tooth does not have to be decreased to allow for shrinkage. However, because of variations introduced by shrinkage of film, this location for the edge guide has the important disadvantage that it makes extremely difficult the provision of rails of adequate width to support the sound-track edge without encroaching on, and consequently scratching, the picture or sound-track area. (See Section 3, Proposals for 16-mm. and 8-mm. Sprocket Standards, Vol. 48, No. 6, June 1947, Journal of the Society of Motion Picture Engineers).

Figure 11 (*continued*)

Proposed American Standard Location and Size of Picture Aperture of 16-Millimeter Motion Picture Cameras	Z22.7- February 1949

The film may be pressed against the fixed edge guide by a spring, by the tendency of the film to tilt in the gate, or by other means. In the second case, there is a fixed guide for each edge of the film. The important point is to have the film centered laterally on the optical axis.

Dimension C is made slightly less than half the width of unshrunk film so that the film will be laterally centered if it has a slight shrinkage at the time it is run in the camera. This is the normal condition. As indicated by the above discussion, C may be measured in either direction from the vertical centerline.

Note 3: Dimension F must be maintained only when a photographic sound record is to be made on the film that passes through the camera; otherwise F may be disregarded.

Note 4: The K dimensions are measured along the path of the film from the horizontal centerline of the aperture to the stopping position of the registration device. Both the dimensions and tolerances were computed to keep the frameline within 0.002 to 0.005 inch of the centered position for films having shrinkages of 0.0 to 0.5 per cent at the time they are exposed in the camera. For any given camera, use the value of K corresponding to the location of the registration device.

If the film does not stop exactly where the film registration device leaves it, because of coasting or some other cause, a slight adjustment of the value of K will be necessary. This will be indicated if film that has a shrinkage of 0.2 to 0.3 per cent when it is run in the camera does not show a properly centered frameline. From such a test, the amount and direction of the adjustment can be determined.

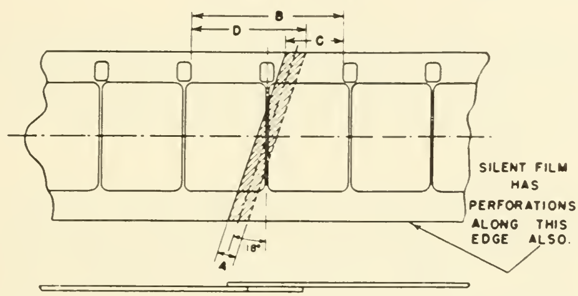
Note 5: "Optical axis of camera" is defined as the mechanical axis or centerline of the sleeve or other device for holding the picture-taking lens. Except for manufacturing tolerances, it coincides with the optical axis of the lens.

Figure 11 (*concluded*)

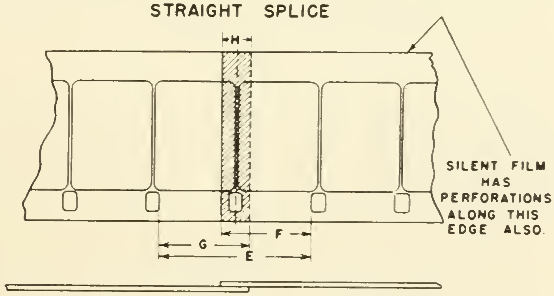
PROPOSED AMERICAN STANDARD FOR SPLICES FOR 16-MILLIMETER MOTION PICTURE FILMS FOR PROJECTION (Third Draft)	ASA Reg. U. S. Pat. Off. SMPE 62 May, 1949 Z22.24

Page 1 of 3 Pages

DIAGONAL SPLICE



STRAIGHT SPLICE



Diagonal Splice			Straight Splice		
	Inches	Millimeters		Inches	Millimeters
A	0.070 +0.000 -0.005	1.78 +0.00 -0.13	H	0.100 +0.000 -0.005	2.54 +0.00 -0.13
B	0.548 +0.001 -0.001	13.92 +0.025 -0.025	E	0.548 +0.001 -0.001	13.92 +0.025 -0.025
C	0.210 +0.000 -0.003	5.33 +0.00 -0.08	F	0.324 +0.000 -0.003	8.23 +0.00 -0.08
D	0.411 +0.000 -0.003	10.44 +0.00 -0.08	G	0.324 +0.000 -0.003	8.23 +0.00 -0.08

NOT APPROVED

Figure 12

PROPOSED AMERICAN STANDARD

FOR SPLICES
FOR 16-MILLIMETER MOTION PICTURE FILMS
FOR PROJECTION

(Third Draft)

ASA
Reg. U. S. Pat. Off.

SMPE 62
May, 1949

Z22.24

Note 1 Splices made in accordance with this standard are primarily for use with films intended for actual projection, such as release prints and reversal films. For negatives and other laboratory films, narrower splices, sometimes with one edge on the frameline. frequently are used.

Note 2 In the plan views, the diagonal and straight splices are arranged with the perforations at the top and bottom, respectively, in order to show them as they appear on most splicers. Either splice may be made with the films turned through an angle of 180 degrees, or any other angle, but of course the emulsion surfaces should always be up. Furthermore, it is customary to scrape the top surface of the left-hand film and to cement this scraped area to the bottom surface of the right-hand film.

Note 3 Dimensions A and H are given only a negative tolerance because if there is to be any variation, it should be toward narrower rather than wider splices. That is in the direction to make the splices less conspicuous on the screen and less likely to affect the normal curvature of film as it follows the bends in its path.

Note 4 Dimensions B and E control the longitudinal registration of the two films being spliced. They are measured to the perforations that are most commonly used for registration on splicing blocks, and to the nearer edges of these perforations because they are the edges that are generally used for the registration. These dimensions were made the same as those in Z22.77, Splices for 8 Millimeter Motion Picture Film, because many splicers are designed to accept either 16 or 8-millimeter film.

Their nominal value was made 0.548 inch instead of the usual 0.550 (for unshrunk film) because the films being spliced are always shrunk to some extent. The 0.548 figure corresponds to a shrinkage of 0.36 percent, while the 0.549 and 0.547 values permitted by the tolerances correspond to 0.18 percent and 0.55 percent, respectively. Thus the tolerances include the range of shrinkage ordinarily encountered when film is being spliced.

NOT APPROVED

Figure 12 (*continued*)

PROPOSED AMERICAN STANDARD

FOR SPLICES
FOR 16-MILLIMETER MOTION PICTURE FILMS
FOR PROJECTION

(Third Draft)

ASA Reg. U. S. Pat. Off.

SMPE 62
May, 1949

Z22.24

Note 5 Dimensions B, C and D and their tolerances were chosen to make the 0.070-inch diagonal splice approximately symmetrical about the frameline when the film is shrunk 0.36 percent. The slight departure from symmetry is to insure that when 8 millimeter splices are made on a combination splicer, the cut ends of the films will not encroach on the adjacent perforations.

Note 6 Dimensions G and F were chosen to give a straight 0.100-inch splice that is symmetrical about the included perforation (and therefore the frameline) when the film is shrunk 0.36 percent. See Note 4.

Note 7 The width of the film at the splice shall not exceed 0.630 inch. If the film has been widened during scraping, the extra width shall be removed.

Note 8 The overlapping perforations of the two films shall not be offset laterally more than 0.002 inch.

Note 9 At the splice, the edges of the two spliced films shall not be offset laterally more than 0.002 inch, unless a difference in the lateral shrinkages of the two strips makes it impossible to maintain that tolerance. Shoulders formed by such misalignment shall be beveled after the cement has dried.

Note 10 In the plan views, the angle between the respective edges of the spliced films shall be 180 degrees, plus or minus 40 minutes. Thus, the spliced film shall be aligned to the extent that when one portion of the film is placed against a straight edge, the other portion will not deviate more than 0.006 inches (approximately the thickness of the film) in 6 inches.

Note 11 In order to prevent the appearance of a white line on the screen, the scraped area shall be 0.001 to 0.003 inch narrower than the area covered by the overlapping film. The presence of this narrow uncemented area will not shorten the life of the splice.

NOT APPROVED

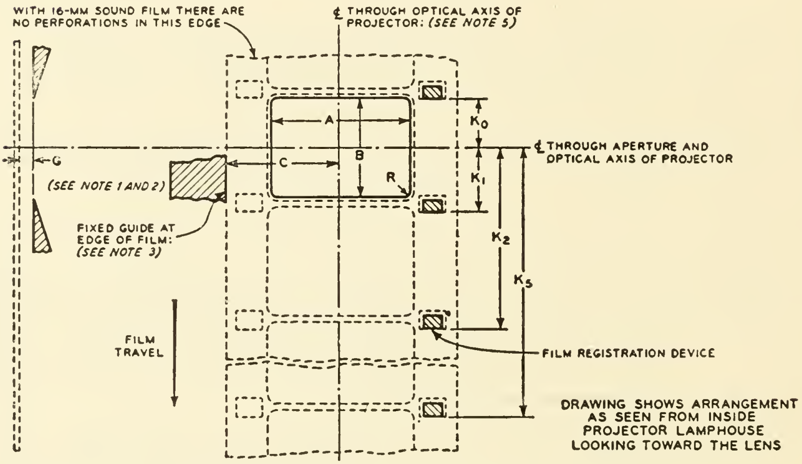
Figure 12 (*concluded*)

Proposed American Standard
Location and Size of Picture Aperture of

16-Millimeter Motion Picture Projectors

Z22.8-February 1949

This standard applies to both silent and sound 16-mm. motion picture projectors. It covers the size and shape of the picture aperture and the relative positions of the aperture, the optical axis, the edge guide, and the film registration device. The notes are a part of this standard.



Dimension	Inches	Millimeters	Note
A (measured perpendicular to edge of film)	0.380 ± 0.002	9.65 ± 0.05	1
B (measured parallel to edge of film)	0.284 ± 0.002	7.21 ± 0.05	1
C	0.314 ± 0.002	7.98 ± 0.05	3
K_0	0.124 ± 0.005	3.15 ± 0.13	4
K_1	0.174 ± 0.005	4.42 ± 0.13	4
K_2	0.473 ± 0.005	12.01 ± 0.13	4
K_3	0.771 ± 0.005	19.58 ± 0.13	4
K_4	1.070 ± 0.005	27.18 ± 0.13	4
K_5	1.368 ± 0.005	34.75 ± 0.13	4
R	0.020 maximum	0.51 maximum	1

Figure 13

Proposed American Standard Location and Size of Picture Aperture of **16-Millimeter Motion Picture Projectors**	**Z22.8- February 1949**

The angle between the vertical edges of the aperture and the edges of normally positioned film shall be 0 degrees, ± ½ degree.

The angle between the horizontal edges of the aperture and the edges of normally positioned film shall be 90 degrees, ± ½ degree.

Note 1: Dimensions A, B, and R apply to the portion of the image on the film that is to be projected; the actual opening in the aperture plate has to be slightly smaller. The exact amount of this difference depends on the lens used and on the separation (dimension G) of the emulsion and the physical aperture. To minimize the difference in size and make the image of the aperture as sharp as practicable on the screen, G should be no larger than is necessary to preclude scratching of the film. When the reduction in size from the image to the actual aperture is being computed, it is suggested a 2-inch f/1.6 lens be assumed unless there is reason for doing otherwise.

Note 2: The limiting aperture is shown as being between the film and the light source so that it will give the maximum protection from heat. If other factors are more important, it may be on the other side of the film.

Note 3: The edge guide is shown on the sound-track edge. This location for it has the advantage that the rails bearing on the face of the film along this edge and also between the sound track and picture area can be of adequate width. Disadvantages of this location for the edge guide are that, because film shrinkage and tolerances affect the lateral position of the perforations, the pulldown tooth must be comparatively narrow and will not always be centered in the perforation. Also, in some prints the sound-track edge is slit after processing, in which case there is likely to be some lateral weave between this edge and the pictures.

The guide can be on the other edge, adjacent to the perforated edge of sound film. With the guide at this edge, the width of the pulldown tooth does not have to be decreased to allow for shrinkage. Also, slitting the sound-track edge after processing will not introduce lateral unsteadiness. However, because of variations introduced by shrinkage of film, this location for the edge guide has the important disadvantage that it makes extremely difficult the provisiôn of rails of adequate width to support the

Figure 13 (*continued*)

Proposed American Standard Location and Size of Picture Aperture of 16-Millimeter Motion Picture Projectors	**Z22.8-** **February 1949**

sound-track edge without encroaching on, and consequently scratching, the picture or sound-track area. (See Section 3, Proposals for 16-mm. and 8-mm. Sproket Standards, Vol. 48, No. 6, June 1947, Journal of the Society of Motion Picture Engineers).

The film may be pressed against the fixed edge guide by a spring, by the tendency of the film to tilt in the gate, or by other means. In the second case, there is a fixed guide for each edge of the film. The important point is to have the film centered laterally on the optical axis.

Dimension C is made slightly less than half the width of unshrunk film so that the film will be laterally centered if it has a slight shrinkage at the time it is run in the projector. This is the normal condition. As indicated by the above discussion, C may be measured in either direction from the vertical centerline.

Note 4: The K dimensions are measured along the path of the film from the horizontal centerline of the aperture to the stopping position of the registration device. It is customary to provide a framing movement of 0.025 inch above and below this nominal position. For any given projector, use the value of K corresponding to the location of the registration device.

If the film does not stop exactly where the film registration device leaves it, because of coasting or some other cause, a slight adjustment of the value of K will be necessary.

Note 5: "Optical axis of projector" is defined as the mechanical axis or centerline of the sleeve for holding the projection lens. Except for manufacturing tolerances it coincides with the lens axis.

Figure 13 (*concluded*)

(*9*) Negative sound track width (fully modulated): the width of a fully modulated variable-area negative sound track is 0.060 in. This width is symmetrically disposed about the sound track center line specified above. (Ref.: ASA–Z22.41.)

(*10*) Projector scanning beam for sound track: the standard projector scanning beam for sound is 0.071 in.; this too is symmetrically disposed about the sound track center line of 0.058 in. Note that the scanning beam width is greater than the negative sound track width; the purpose of the dimensional difference is to allow for the various errors in placement and in weave that will occur in all machinery used between the original sound record and the release print derived from it. (Ref.: ASA–Z22.41.)

(*11*) Printed area for sound track of a release print: the standard printed area for printing a sound release print from a variable-area negative is 0.080 in. (minimum); this area is symmetrically disposed about the 0.058 in. center line. Additional printing area is permitted toward the picture, up to 0.012 in. The relations between these dimensions are shown in ASA–Z22.41. Note that the printer aperture width is greater than the scanning beam width of the projector; the purpose of this dimensional difference is to allow for the various errors in placement and in weave that will occur in all machinery used between the original sound record and the release print derived from it.

(*12*) Direct positives—picture and sound: it should be noted that although the formally adopted standards for the picture portion of the film have taken direct positives into account in addition to negatives, no standards have yet been adopted that take into account direct positives of sound. Only sound by means of negative–positive processing has been anticipated up to this point. The guiding rule for sound effectiveness is: "Will the finished product—the print—project properly in a standard 16-mm projector?" Just as long as that is accomplished, the objectives of the recording, printing, and processing processes are being attained.*

Checking Sound Track Dimensions

Introduction

The checking of dimensions on motion picture films can clear up many practical difficulties that might otherwise remain quite obscure. With a knowledge of current standards and with relatively simple test apparatus, such as the Bausch and Lomb Shop Microscope mentioned previously, most dimensional difficulties arising from the picture and its handling can be readily tracked down. Since sound and its handling often seems somewhat more obscure to many people, a more detailed treatment of the checking of sound-track dimensions seems worthwhile.

If sound is to be recorded satisfactorily, it must be recorded correctly with respect to dimensions. This means that aperture widths, aperture locations, and film weaves must be checked. Sound originals should

* Data on new arrangements that are in use but have not been standardized should be promptly transmitted by anyone interested to the Engineering Secretary of the Society of Motion Picture Engineers at 40 West 40 St., New York, N. Y., for suitable consideration in connection with standardizaton.

be measured as a routine matter; if an original is found that is beyond the tolerances specified, the original should be scrapped and a new one produced. It is not wise to take anything for granted. Never assume any dimension to be correct. Measurement is quite simple and provides a direct yes-or-no answer.

Let us assume that it is necessary to check through the complete process. The starting point is a 16-mm sound recording machine using the same lot of film that is to be used in production. The test film should be developed in the same laboratory as the production film and under the same development and other conditions. Only in this manner will the result have a bearing on actual practice.

Part 1: Locating the Center Line of a Sound Track Negative

Introduction. The basic dimension for all sound film is the center line; its location is 0.058 in. from the guided edge of the film. Because 16-mm sound-recording machines are usually designed to propel film in either direction, it is not unusual for the center line to assume two different positions; the position on a particular strip of film depending

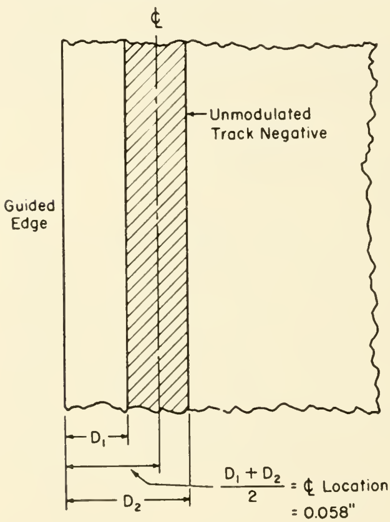


Fig. 14. Location of negative sound track center line. No signal—no bias.

upon the direction of travel of the film through the recording machine. The difference in center-line location between "A" winding film and "B" winding film run through the same machine may be of the order of 1 or 2 thousandths of an inch; in poorly-designed machines the difference may be much greater.

Certain designs of recording machines (such as machines with little guiding near the point of sound translation) may produce sound tracks

that weave badly until the machine is up to speed and "settled down"; other designs may produce sound tracks that are badly out of location at the start and drift into place over various lengths of film. These are all defects that can be quickly detected by measurement.

Checking the Center Line. Record a few feet of unmodulated negative track; it is convenient to make this record with the noise–reduction (AGN) bias turned off. After having the film developed in the customary way, measure the distance D_1 from the edge of the film to the closer trace of the sound track as shown in Figure 14. Measure the distance D_2 from the edge of the film to the far trace of the sound track. The center line is $(D_1 + D_2)/2$ from the edge of the film. To reduce error, it is desirable to make at least four sets of such measurements and to use the arithmetic average as the basic dimension in further calculations. As measured, the center line should be not less than 0.057 in. nor more than 0.059 in. from the edge of the film. It is wise to check the recording machine with both "A" and "B" winding film; the best center-line setting is the setting in which one location is just as much over the 0.058-in. nominal dimension as the other location is under the 0.058-in. nominal dimension. ASA–Z22.75 is the applicable standard for "A" and "B" winding. (See Chap. VI.)

General Notes on the Center Line. It should be obvious that the center line of a negative sound track should coincide with the center line of the projector scanning beam, and also with the center line of the sound track print made from that negative. This is true not only of direct 16-mm films but also of 16-mm prints made by optical reduction from 35-mm originals. The general method described can be applied to any center-line measurement of sound film.

Measuring Instruments. The instruments chosen should depend upon the required accuracy and convenience of operation. For occasional checking, the Bausch and Lomb Shop Microscope (Cat. #31-29-33-34, code word *Ahupo*) is an excellent instrument; its price is about $50. For more accurate measurement, the B & L Toolmaker's Microscope is distinctly better, but usually too high in price to justify the relatively small improvement in usefulness.

Conclusion. Generally speaking, if the center line of the recording machine was properly set at the factory, it is likely that there will be but little change if the machine receives normal maintenance and care. All rollers should turn freely, just as when the machine was new. The machine should always be protected from dust and dirt; the door should be fully closed and a dust cover placed over the machine when not in use. The surface of rollers should be cleaned lightly with carbon tetra-

chloride (Carbona) and the bearings of the rollers lightly oiled occasionally—as directed by the manufacturer. If these simple precautions are observed and the machine is sent back to the manufacturer once each year for check-up and readjustment, there should be no difficulty in maintaining the correct center-line dimension of 0.058 in.

Part 2: Checking the Width of a Negative Sound Track

General. The intelligence conveyed by a sound track to a listener results from the variation in light transmitted through the sound track when the latter is scanned by a projector sound track scanning beam. The varying light which is transmitted through the film is customarily directed to a photoelectric cell.

Track Width. It should be apparent that there is a maximum width of recorded track that can be accommodated without technical difficulty.

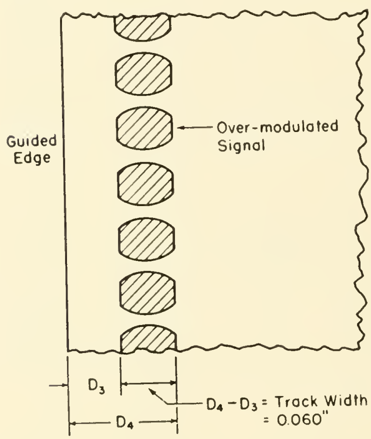


Fig. 15. Determination of width of negative sound track. An oscillator signal overloads the modulator.

The standard width for a 16-mm sound negative is 0.060 in., 0.030 in. on either side of the center line.

Checking the Track Width of a Recording Machine for Sound Negative. Record a few feet of modulated sound track with the bias and the compressor turned off, and with a 1000-cycle tone from an oscillator strong enough to give a volume indicator reading of plus 6 db beyond full modulation. This will produce a record that is "overshot"; such a record is certain to show maximum track width on the film. After developing the film, measure the distance D_3, as shown in Figure 15 from the edge of the film to the closer trace of the sound track. Measure the distance D_4 from the edge of the film to the far trace of the sound track. The width of the sound track is $D_4 - D_3$; the correct value is 0.060 in.

It is wise to check this dimension because certain older machines have appreciably wider apertures. Certain RCA recording machines had apertures 0.064 in. wide; it was agreed in the War Committee on Photography and Cinematography (Z52) and further continued in the Z22 Committee dealing with post-war standards that maximum modulation width should be limited to 0.060 in. in all new equipment manufactured, and that existing equipment be modified to meet the 0.060-in. dimension. (See asterisk note on Z22.41–1946.) Track width should not be less than 0.059 in. and not greater than 0.061 in. Prints made from a 35-mm sound original by optical reduction or by any other means are expected to have such dimensional characteristics that they might have been made from an equivalent 16-mm sound negative of ASA standard dimensions.

Part 3: Initial Bias Setting for a Sound Negative

General. The initial bias setting is an adjustment of the noise-reduction equipment (called variously AGN—anti-ground-noise, GNR—ground-noise-reduction, NR—noise-reduction or noiseless-recording, or "bias" equipment) that is necessary to effect "noiseless recording." The light transmission through a print made from a properly recorded "noiseless" negative is at a minimum when there is no signal; the average transmission of the print when a signal is present is made approximately proportional to the amplitude of the signal.

Since the bias that controls the average transmission of the film is customarily derived from the signal itself, it is evident that the bias current is produced slightly later than the time at which the signal is applied; the time interval can be called the actuating delay time. Other current terms describing the same time interval are: attack time, opening time, unlocking time, etc. The actuating delay time of a bias amplifier is in the order of a thousandth of a second. If a sound signal is suddenly applied (a pistol shot, for example) the signal would arrive at the recording galvanometer before the bias current; if the initial bias setting were made for zero track width, distortion would result because the recorded waves arriving before a millisecond had passed would be cut off and distortion would result. If, however, the track width at zero signal were set for some arbitrary value such as 0.005 in. on conventional equipment, an operating "margin" would be provided that would permit most ordinary sounds to be recorded without the serious distortion that results from "chopping off the waves." In a

sense, the initial bias setting of 0.005 in. would provide the approximate equivalent of the actuating delay time of the signal.

The best initial bias setting depends upon the character of the sound to be recorded. Experience has indicated that the setting of 0.005 in. is satisfactory for most kinds of recorded sound recorded upon most kinds of sound-recording equipments.

Checking the Initial Bias Setting of a Recording Machine. With the microphone and other input keys turned off, and with the gain controls and other signal controls set for zero signal, record a few feet of negative (3 to 5 ft.) at rated bias current as well as at several settings above and below rated current. (In the case of a Maurer Model D equipment, settings at 24, 26, 28, 30, 32, and 34 milliamperes are suit-

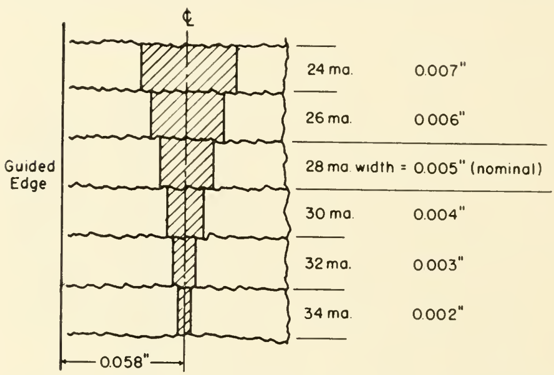


Fig. 16. Measuring the unmodulated noise-reduction negative track widths obtained with various bias currents. Current values shown are typical of Maurer sound recording machines. A width of 0.005 in. is recommended.

able.) Keep a log sheet so that each test recording may be identified quickly. After having the film developed, indicate the width of each section of track so produced in the appropriate place on the log sheet. Select the AGN current that provides an initial bias track width of 0.005 in. See Figure 16. Widths are measured on the recommended microscope or equivalent measuring device. Initial bias track width is not critical; if the initial bias setting is once measured and noted, there will be little need for change in the milliampere setting during the normal machine life. If the setting is maintained within plus or minus one milliampere, there should be little cause for concern about this adjustment.

Part 4A: Measuring the Scanning Beam of a Projector for Center Line and Width

General. The design of a good sound-translating system in a sound projector brings an engineer-designer face to face with a dilemma. For

locating the film accurately with respect to the scanning beam, a guide should be placed where the scanning beam impinges on the film. On the other hand, the requirement of best film motion dictates that the guide shall be as far as possible from the point where the light beam impinges upon the film. It is for such reasons that the standards take the possibility of weave into account and have allowed for greater weave in sound projectors than in other machinery involved in the making and reproducing of 16-mm sound film.

The recommended width of a projector scanning beam is 0.071 in. The center line of this beam should be located 0.058 in. from the edge of the film, as described in Part 1. A quick qualitative check of a machine may be made by playing back an SMPE Buzz Track Test Film; this film has a tone of one frequency recorded beyond one limit of the sound track scanning beam, and a tone of different frequency recorded beyond the other limit of the sound track scanning beam. For measurement, however, the following procedure is suitable.

Checking the Projector Sound-Scanning Beam. The general method is to expose fine-grain positive film in the projector, develop the film, and to measure the track so produced. Obviously, all operations that involve exposing the film must be conducted in a dark room. Turn on the projector; run it without film for a few minutes. While it is running, extinguish all lights except the exciter lamp. The lights to be extinguished include all pilot lights, the picture projection lamp, etc. Shut off the machine. Wind approximately 100 ft. of fine-grain positive film on a reel in such a manner that when the reel is placed on the feed arm of the projector, the emulsion will face the screen. Make certain that the sound optics are correctly set for this emulsion position. Most machines do not provide an adjustment for nonstandard emulsion position films. Thread the projector. Turn on the amplifier so that the exciter lamp is lit. (If your machine is one of the older models that alters the brightness of the exciter lamp to effect volume control, set the volume control at the setting ordinarily used for ordinary black-and-white prints.) Run the film through the projector. After takeup, rewind the film on a core, wrap it, put it in a sealed film can, and send it to a film laboratory for development. An explanatory note should be sent with it explaining just what the film is and how it is to be developed. In most cases, developing at "standard" release print positive developing time will be satisfactory.

On the developed film, measure D_5 from the edge of the film to the

nearer trace of the track. Measure the distance D_6 from the edge of the film to the far trace of the track. The width of the track $(D_6 - D_5)$ should be 0.071 in., if the machine is built within the standards, the track width will fall between 0.070–0.072 in. The distance of the center line from the edge of the film should be 0.058 in.; the method of measuring is described in Part 1 of this chapter. See Figure 17.

If the traces are quite fuzzy due to overexposure, it may be wise to use EK 5365 (fine-grain duplicating positive film) for the test, or some other relatively slow film of high resolving power. Other films that may be suitable are EK 5372 and Eastman or DuPont microcopy (nonpanchromatized). Incidentally, some microcopy film is panchromatized to increase its effective speed; because panchromatic emulsions fog under

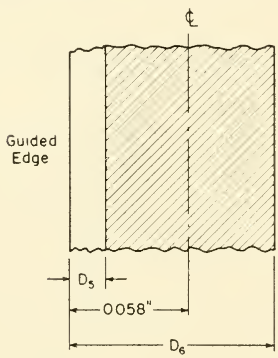


Fig. 17. Measuring width of projector scanning beam. Film is measured after exposing raw stock in the projector and developing it. $D_6 - D_5 = 0.071$ in. (nominal).

red light, positive-type emulsions without color sensitizing are best suited to the purpose. A really desirable film would be a chromatically unsensitized microcopy emulsion coated on a clear base. It may be difficult to obtain such a film commercially; if it is, other types somewhat less desirable may have to be used. At least 16 sets of readings of D_5 and D_6 should be made along the central 50-ft. portion of the 100-ft. roll, both readings being made at the same point along the film. The center-line reading is the arithmetic average obtained from the 16 sets.

In general, it is a good plan to take a relatively large number of readings, since the probable error of the average is proportional to the square root of the number of observations. Generally speaking, the number of reading sets should be 4, 9, 16, 25, 36, 49, 64, etc.; the actual number taken being dependent upon the probable error desired. For most purposes, 16 sets will usually be sufficient.

Part 4B: Measuring the Scanning Beam of a Projector for Weave

General. In facing the design dilemma described in the preceding part, the engineer draws upon all his ingenuity. The result that is actually achieved represents his chosen compromise between the two opposing design factors. The effectiveness of his design is measured by two criteria: (*1*) the smoothness of the film motion at the scanning beam, and (*2*) the weave of the film as it passes the scanning beam. Weave may be defined simply as the deviation of the film from its nominal or average path of travel.

Weave Measurement. If a film tends to move first toward one edge of the projector scanning beam at one instant, and then move toward the other edge at the next instant, it is apparent that we can not rely upon a single set of readings to determine the mean location of the center line. Should we attempt to do so, it is probable that we would obtain some measurement other than the average center line dimension. Our reading might occur at either extreme or at any point between these two limits. There is no way of predicting just what a single set of readings may mean. It is necessary to take a relatively large number of sets of readings (16) at different points along the track and to calculate the averages. Among the sets of readings so taken there will probably be a set of values reasonably representative of the extremes. Thus, since weave is customarily expressed as a maximum value rather than an rms* value or as an arithmetic mean, the weave may be taken as the average of the difference between the largest and smallest D_5 readings, and the difference between the largest and smallest D_6 readings.

$$\frac{D_{5(max)} - D_{5(min)} + D_{6(max)} - D_{6(min)}}{2} = \text{Weave}$$

No standards have been established for weave. Weave in a good recording machine, film phonograph, or printer with good guiding is less than 0.001 in. Weave in a good projector should be less than 0.003 in. If the weave in the projector is 0.005 in. or more, get in touch with the manufacturer and have it repaired.

Part 5A: Measuring a Positive Print for Center Line

Introduction. When a positive print is made from a sound track negative, it is necessary that the printing aperture be not only wider

*The rms is the root mean square.

than the track width of the sound negative (see Part 2), but also wider than the scanning beam of the projector (see Part 4A). The accepted dimension for track width of a positive print is 0.080 in.; the center line of the track is 0.058 in. from the reference edge of the film.

Most laboratories use a printer aperture wider than 0.080 in. In one laboratory, for example, a printing aperture of 0.105 in. is used; the 0.025 in. of additional width is provided only on the side of the aperture toward the picture. This wider aperture is considered necessary because of the inaccuracies in the scanning beams of certain of the older sound projectors that are still in use. Although the maximum value for the scanning beam width is 0.072 in., some of the early machines such as

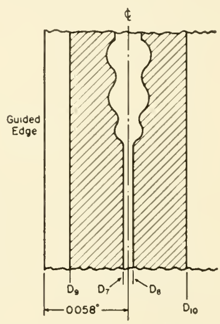


Fig. 18. Sound track of positive print. Measured for (*a*) center line, (*b*) printer aperture, and (*c*) weave. Center line $= (D_8 + D_7)/2 = 0.058$ in.; Printer aperture $= D_{10} - D_9 = 0.105$ in. (Common values are: $D_{10} = 0.117$ in., $D_9 = 0.012$ in.); Weave $= [(\text{Max. } D_{10} - \text{Min. } D_{10}) + (\text{Max. } D_9 - \text{Min. } D_9)]/2$.

the old Victor Animatograph Sound Projectors had beams as wide as 0.085 in.

The use of a printer aperture wider than 0.080 in. represents an attempt on the part of a laboratory to reduce the noise produced when good prints are run on nonstandard projection machines. When all projectors in use will have the standard width scanning beam properly located, laboratories will be able to reduce the printer aperture width to 0.080 in.

Measuring the Center Line. It will be observed that a bilateral sound track print from a negative has two black areas separated by a white area. Measure the distance D_7 from the edge of the film to the far boundary of the near black area. Measure the distance D_8 from the edge of the film to the near boundary of the far black sound track area (see Fig. 18). The center line dimension is equal to one-half the sum of D_7

and D_8. Use the average of 16 readings of D_7 and the average of 16 readings for D_8. In a good printer the misplacement should not be more than 0.001 in. Needless to say, the misplacement error of no two printers is alike; misplacement error cannot be considered the same in all prints made on all printers in any particular laboratory or in different laboratories. Machines with positive guiding means, such as optical one-to-one sound printers, will ordinarily show but little guiding error; the guiding error in continuous contact printers is appreciably larger. If printer misplacement exceeds 0.002 in., the offending machine should be taken out of service and readjusted.

Part 5B: Measuring a Positive Print for Printer Aperture and Weave

General. The design of a good printer requires the same sort of design compromise as does a projector; generally speaking, the result to be expected in a sound printer is appreciably better than from a sound projector, since the price is much higher.

Checking Printer Aperture Width. The printer aperture width is $D_{10} - D_9$ (Fig. 18). 16 sets of readings are taken, and the averages of the D_{10} and the D_9 readings are used. On much equipment, D_{10} is 0.117 in. and D_9 is 0.012 in. for black-and-white prints made from a sound negative. As mentioned in Part 5A, printer aperture width will probably be reduced at some time in the future when all nonstandard projectors have been retired from service or have been repaired and corrected.

Checking Print Weave. Print weave may be considered to be the arithmetic average of the difference between the largest and smallest D_{10} readings, and the difference between the largest and smallest D_9 readings. If the weave found in the print is compared with the weave found in the negative, the difference represents the weave in the printer.

Conclusion. Since the weave found in a really good sound-recording machine is quite small (usually less than 0.0005 in.), a sound negative of good quality can ordinarily be used to check weave in other machinery, such as projectors and printers. Unfortunately, the high order of accuracy of location and the low order of weave found in good sound-recording machines is rarely found in other kinds of sound-film equipment. Poor equipment maintenance often complicates the problem of accurate location and low weave, for this reason it is usually a good rule to check dimensions of all available films and machines to make certain that they

are dimensionally correct. If printer weave exceeds 0.001 in., the source should be traced and the difficulty corrected.

Part 6: Measuring the Sound Track of a Color Reversal Print (Kodachrome Duplicate)

General. It must be remembered that a Kodachrome duplicate is a direct positive that has been derived in most cases by printing on Kodachrome from a positive. If there were no misplacements or weavings in the printers, projectors, or other machines used to make, copy, and reproduce the film, the printer aperture required for a Kodachrome duplicate would be exactly the width of the aperture of the sound recorder. Unfortunately, this ideal state of affairs does not exist; allowance must be made for the various misplacements and weave that occur in all the machines used to produce and project the film. If the misplacements and weaves to be expected are small, only small allowance need be made; if the misplacements and weaves are large, correspondingly large allowance must be made. Since the sound track should be completely scanned by the scanning beam of the projector, the total misplacement plus weave should be not more than the difference between the projector scanning-beam width and the recorder light-beam width. Thus for Kodachrome printing, the printer aperture should be larger than 0.060 in. yet smaller than 0.071 in. Since some RCA and other sound-recording machines may not have been modified from 0.064-in. recording-machine aperture width to the standard value of 0.060 in., a possible suitable value for printer aperture width in this case might be 0.0675 in., which value could be reduced in the near future to 0.0655 in. or even smaller. Many optical reduction films will have an equivalent 0.064-in. sound track because the original 35-mm sound track has a 0.076-in. width, and the uncorrected optical reduction sound printer has a reduction ratio of 7 to 6.

The use of a printer aperture wider than the minimum necessary causes the introduction of unnecessary noise in reproduction. The projector scanning beam scans a portion of the film on which no sound has been recorded; yet the density of that added portion is low enough to cause modulation of the transmitted light beam by dirt, grain, irregularities, and other noise-producing elements. As in the case of all other similar apertures, the printer aperture for printing sound on Kodachrome or AnscoColor should be symmetrical with respect to the center line of the film.

Checking Dimensions. Measure D_7 and D_8 on the color duplicate.

The center line $(D_7 + D_8)/2$. Measure D_{12} in the manner of D_{10}. Measure D_{11} in the manner of D_9. The aperture width is D_{12} minus D_{11}. The weave is the difference of the extreme values; as previously, it is taken as the arithmetic average.

Reasonable values for these measurements are: center line—0.058 in.; aperture width—0.067 in.: weave—0.001 in.

The difference between the weave found in the Kodachrome duplicate and that found in a sound positive from which the duplicate was printed represents the weave of the printer as well as the weave introduced in printing the duplicate.

Selected References

American Standards Association, ''Price List of American Standards'', current issue, see listings for Z22 (motion pictures), Z38 (photography other than cinematography), and Z52 (photography and cinematography—American War Standards).

Additional references may be found in the following JSMPE indexes:

July 1916 to June 1930

''Standardization,'' page 149.

''Standards and Nomenclature,'' page 150.

January 1930 to December 1933

''Standardization,'' page 65.

''Standards and Nomenclature,'' page 65.

''Standard Test Reels,'' page 65.

1936 to 1945

''American Standards Association,'' page 73.

''SMPE Activities,'' page 128.

''Standards,'' page 148.

''War Committee on Photography Z52,'' page 155.

CHAPTER VI

The Problem of 16-Mm Emulsion Position

Introduction

As pointed out in Chapter III, a conventional 16-mm motion picture film consists essentially of an image-recording emulsion approximately 0.001 in. thick, coated upon a mechanical support—called the base—which is approximately 0.005 in. thick and is usually clear. Thus, the image is confined to the emulsion which is only one-sixth or so of the total thickness of the film.

What is more important is that the image is located on only one of the two surfaces of the film base. This almost obvious fact which is implicitly presupposed and rarely stated explicitly is the crux of the emulsion position problem despite the fact that there are other known considerations that are not presupposed. One such consideration relates to the use of a form of light-sensitive film called Ozaphane* (one of many trade names) in which the light-sensitive, color-forming, diazo dyestuffs are mixed with the base-material components prior to their manufacture into sensitized-sheet photographic film. Since these dyestuffs are uniformly distributed throughout the base, it would be advantageous from the optical engineer's point of view if the base material could be made very thin, about 0.001 in., so that for practical purposes the photographic image would be located in a thin plane rather than spread out through a relatively thick solid as it would be viewed by a light beam that traverses the image-registering film. From the optical engineer's point of view, the coated emulsion of the conventional film is already only about 0.001 in. thick, and the design advantage of reducing either the emulsion thick-

* It is interesting to note in passing that Ozaphane films are developed in ammonia gas. Such development has a number of advantages which include:

(*1*) A positive is made directly from a positive without need for chemical reversal.

(*2*) Since no water is used for developing solutions, the dimensional changes due to development are small compared with conventional silver film developing methods.

(*3*) The image is a colored dye that is substantially grainless and has a high resolving power.

(*4*) Sensitometrically, one of the films has a shoulder but no toe to its density—log exposure curve.

ness or the base thickness is somewhat problematical in view of the many practical machine design and manufacturing problems that would be raised by such a change. Current commercial practice is "frozen" to the use of coated films of roughly 0.006-in. thickness for 16-mm sound motion picture purposes.

History

When the original emulsion position problem was first considered in connection with 16-mm standardization a number of years ago, it was the belief of the majority concerned that reversal original films of amateur and related origins used for direct projection would be of primary importance in 16-mm. Accordingly the present standard emulsion position was agreed upon. Since, in a camera, the emulsion on the film faces the lens of the camera, the emulsion would face in the same direction (toward the lens of the projector) because the identical piece of film was used in the projector that was exposed in the camera.

Original reversal film failed to materialize as the sole source of 16-mm films, and when sound made its appearance in 16-mm films optically reduced from 35-mm entertainment and like films, all reduction printing equipment for copying 35-mm to 16-mm was adjusted to produce only prints of standard emulsion position. A relatively large volume of optically reduced prints appeared, and, since the time of their first appearance, almost all such prints have had the standard emulsion position because all optical reduction printing equipment and processes since used have been similarly adjusted.

As films were improved and the costs of 8-mm films and equipment progressively lowered, the cost of 16-mm film and equipment seemed high for strictly casual amateur uses. 8-mm film and equipment quality has since advanced to such a degree that amateur interests have to an important extent transferred to this medium, while 16-mm today is developing as a professional medium. We must, therefore, consider the question of emulsion position in the light of the fact that most 16-mm sound films produced from 16-mm originals are of nonamateur origin.

Emulsion Position in 35-Mm Practice

When 35-mm negative is threaded in a camera, the emulsion of the film faces the camera lens. After development, when the negative is contact-printed, the emulsion of the print stock is exposed to the print-

ing light in contact with the emulsion of the developed negative. When the developed print is threaded in a 35-mm projector, the emulsion on the print is on the side opposite that of the negative, and therefore the emulsion of the print faces the light source of the projector. This emulsion position is called the 35-mm standard emulsion position. When 35-mm film is used, its application, so far as emulsion position is concerned, is quite simple. All original 35-mm black-and-white picture is taken as negative, and all prints are made by contact-printing or the equivalent upon positive raw film. Despite the rapid and continued growth of the industry—including, even, the introduction of sound and color—the 35-mm medium still remains a typically negative-positive medium just as it has been for some forty years or more. Where optical printing and other special processes have been used with 35-mm film as in Technicolor, for example, all these have been so designed and arranged as to conform with the requirements of negative-positive handling.

American and international standards recognize the 35-mm standard emulsion position as the one and only emulsion position to be used in 35-mm release prints. Once a projector has been installed in a theater and adjusted to give the proper size picture, and to scan the sound track in proper manner, no further adjustment is required except for maintenance. Almost any 35-mm film received for projection—regardless of whether it is in color or in black and white—will automatically be in proper focus for both the picture and the sound; there are very few nonstandard emulsion position 35-mm films released for commercial use.

Since negative-positive processing always has been the only processing generally available for 35-mm, it was only natural that the jargon of the industry would take acount of that fact. It is not uncommon, therefore, for the terms "original" and "negative" to be used interchangeably in 35-mm "slang." Many who are beginning to work in both the 16-mm and the 35-mm media after having worked previously only in the 35-mm medium, attempt to carry over the interchangeability of terms to 16-mm even when the use in that manner is definitely in error.

Early History of 16-Mm Reversal Film

In about 1924, the Eastman Kodak Company first marketed 16-mm reversal film. To encourage amateur movie making, it was necessary to reduce the cost of the product to the user by eliminating if possible the second piece of film, the print, that was formerly needed for projection Previously all 16-mm film had been negative-positive.

Reversal had two important commercial advantages. (*1*) The identical piece of film that was exposed by the customer was returned to him for projection. This avoided misunderstandings when unexposed or underexposed films were shipped to the film manufacturer for processing. (*2*) No print was needed for projection. Eliminating the need for the print saved the cost of the raw film for the print, the cost of printing, and the cost of developing the print. This represents a very important saving.

Reversal was recognized in our 16-mm standards by the caption: "In the projector, the base (not emulsion) side of the positive made . . . by the reversal process . . . faces the light source." It is worthy of note that reversal dupe prints began to be commercially important as early as 1931; their importance increased with the marketing of color dupe prints and composite color dupe prints a few years later. Several years had passed, however, before they were given attention in standardization. Since the standardization problems associated with direct positives have not been solved as yet, the subject of 16-mm emulsion position is due for considerable attention now because of the very rapid growth in the volume and dollar value of nonstandard emulsion position prints—both in motion pictures and in television.

Reversal and Color Reversals—What They Are

In the broadest sense, a reversal may be most simply defined as a direct positive. A study of the relative graininess of optical reduction prints from 35-mm negatives in comparison with step-contact prints from 16-mm original reversal appeared in November, 1940. This comparison shows reversal original materials at least equal to 35-mm negative for the making of 16-mm prints.

As has been mentioned previously, Kodachrome has several further advantages as an original film material for 16-mm picture that can hardly be overlooked. Not the least of these advantages is that good composite color dupe prints may be turned out in a laboratory concurrently with excellent black-and-white prints derived from the same originals. This is possible because the composite color dupe prints are manufactured from either the color positive picture original (or an intermediate master color duplicate) and from a positive sound track, while the black-and-white prints are being manufactured from a black-and-white duplicate negative of the picture and a black-and-white sound negative.

Early History of 35-Mm Sound Film

When sound film was commercially introduced in 1929, it was forced to adapt itself to the current negative-positive procedure of the 35-mm picture. It is obvious that if the sound is to appear on the same piece of film with the picture in the composite print, both picture and sound must ordinarily be developed in the same developer bath. Thus, sound-recording procedure in 35-mm was pinned down to a negative-positive procedure to conform with the processing of the picture. Making release prints from original sound negatives was satisfactory only as long as the individual scenes in the sound negative were quite long, requiring but few splices in a reel.

In the earlier sound films, scenes were quite long—often as much as two minutes. As the sound motion picture developed, the length of the average scene became shorter and shorter until now it is considerably less than one-tenth of its length in 1929. For this and other reasons, a demand for re-recording and for lip-synchronization grew. This implied a large number of scenes per reel, and, consequently, a large number of splices in the original sound negative. It was only logical to expect that the industry would attempt to produce some form of direct 35-mm sound positive which, when re-recorded, would eliminate one copying step between the original sound track and the release print.

In the case of sound, however, reversal film did not come to the rescue as it did for the 16-mm picture in 1924. The turbidity of the film emulsion produced serious distortion when the film was reversal-processed. In the literature are to be found numerous papers on the subject of envelope and other types of distortion in which turbidity plays an important part. This distortion effect in a negative has been overcome to a great extent commercially by attempting to produce an equal and opposite effect in the print by the choice of suitable exposure and of suitable development of the print. This procedure has been more or less successful and is preferred today regardless of the materials used. It is most desirable to select emulsions of least turbidity for sound; in practice this means the selection of the material of highest resolving power consistent with the available exposure.

An attempt was made to record directly on positive film with the recording system optics and the electrical circuits so modified as to produce a direct positive by development of the film in a positive bath such as that used for release prints. The distortion in the direct positive so made on the best available raw stock was low enough to be satisfactory. For

purposes of identification we shall call this form of direct-positive sound recording "optical reversal" to distinguish it from chemical reversal While the term is not strictly correct, it will be assumed to include variable-density direct positives such as variable-density toe-recorded sound film.

The really successful direct positives require film of the finest grain and highest resolving power. For various reasons which include the difficulty of obtaining sufficient exposure, direct positives* had not been widely adopted. The customary procedure is to record the original sound as a negative, edit it, make a 35-mm positive print, and then re-record, making a 35-mm sound release negative from which the release prints are made.

Early History of 16-Mm Sound Film

After the initial failure in 1930 of 16-mm sound negatives made by re-recording from a 35-mm print, direct 16-mm sound remained dormant for a number of years. A 16-mm sound camera put in its appearance in 1932; it was operated by the single-system method. As far as the sound was concerned, this unit fell heir to the poor resolution encountered in the commercially unsuccessful re-recording attempts of 1930. The film used did not have sufficiently high resolution since it was a negative type best suited to the picture and poorly suited for variable-area sound recording.

It became evident that the only practicable solution in 16-mm would be double-system recording—just as it had been the solution in 35-mm sound recording. It was not long afterward that 16-mm double-system sound recorders were put on the market. Plans were formulated for their marketing as early as 1936.

Current Status of Direct 16-Mm Sound

By far the largest volume of direct 16-mm sound is produced by the double-system method with negative-positive processing of the sound track. Studies have been made of the application of reversal processing to sound, but it has been the accepted opinion so far that emulsion turbidity and the difficulty of simultaneous control of picture and of sound quality prevents any straightforward use of the distortion-cancellation

* Since the advent of television, however, this long-neglected procedure has received much impetus due to the recent improvements in films for sound recording, and in sound-recording machines.

technic that we daily find so valuable in variable-area negative-positive 16-mm commercial operations. This factor becomes increasingly important as the number of copying operations between the original and the release print increases. For the present, the foregoing may be considered true of variable-area sound with which there has been more commercial experience in the 16-mm film. Reversal processing has had some degree of technical success for 16-mm variable-density sound although it is not widely used.

Direct positive 16-mm sound records are becoming increasingly important since the demands for better sound quality are becoming more insistent. As will be pointed out in Chapter VIII, the direct positive form makes possible the elimination of a transfer step in the copying process, and can result in improved performance because the losses due to the extra transfer step are avoided.

Kodachrome Sound Duplicating and Its Implications

At the present, sound to be duplicated on Kodachrome is still often recorded as a negative—a black-and-white print is made from that negative—and the print used as the sound track positive for printing the composite color dupe print. For the purposes of this discussion, it makes little difference whether the original sound track is recorded on 35-mm film or on 16-mm film.

It is possible that one of the reasons for so few direct sound positives used for Kodachrome printing of composites in the past has been the excessive turbidity of generally available emulsions. Not all positive materials have this handicap; Eastman 5372, being fine-grain, shows this effect to a pleasantly small degree. Much research and development work is being carried on by the film manufacturers to design even better types of film. The results obtained so far hold much promise for the future.

Emulsion Position in 16-Mm

It can be seen from the foregoing that the 16-mm emulsion position problem cannot be adequately dealt with in a casual manner. Reversal and color reversal which are practically nonexistent in 35-mm motion pictures are used almost to the exclusion of negative for 16-mm picture originals. Kodachrome composite color dupe prints, of which there are possibly a million feet or more used per week in 16-mm do not exist at all in 35-mm.

16-mm sound prints may be produced by a wide variety of methods. One possible classification is as follows:

Class 1—Film Width of the Original.
1. Both originals on 35-mm.
2. Both originals on 16-mm.
3. A combination of 35-mm and 16-mm.
   a. 35-mm picture with 16-mm sound track.
   b. 16-mm picture with 35-mm sound track.
   c. Both widths of picture with one or both widths of sound track.

Blowups (enlargements) of picture from 8-mm to 16-mm are quite common already; it is possible that these will become quite important in the future.

Class 2—Sound Recording Processes.
1. Variable density—Full width, squeeze, push-pull class A, class B, class A-B (with or without noise reduction).
2. Variable area—unilateral, bilateral, duplex, push-pull class A, class B, class A-B multiple (with or without noise reduction).
3. Combinations of variable area and variable density (not in wide use except for squeeze).

Class 3—Film Processing Methods.
1. Negative-positive processing (where the tonal aspect of the image is inverted in printing). 2 films—2 developer baths.
2. Second exposure or reversal processing (where the tonal aspect of the image is inverted in developing) a single film—2 developer baths.
3. Single exposure direct-positive processing (where the image is inverted optically or electrically). 1 film—1 developer bath.

Combinations of these classes are not at all uncommon; they are likely to become even more common in the future. Standards, when approved, should be comprehensive and encompass any reasonable combination of any or all of the preceding film widths, processes, and methods. Of greatest importance at the present time are the following:

(*1*) Reduction of 35-mm films—both picture and sound—to 16-mm.

(*2*) Combinations of a 16-mm original with a 35-mm original such as (*a*) Kodachrome 16-mm picture and 35-mm sound track and (*b*) 35-mm picture negative with 16-mm sound track.

(*3*) Direct 16-mm with picture original a negative, reversal, or color positive with sound original a negative or direct positive.

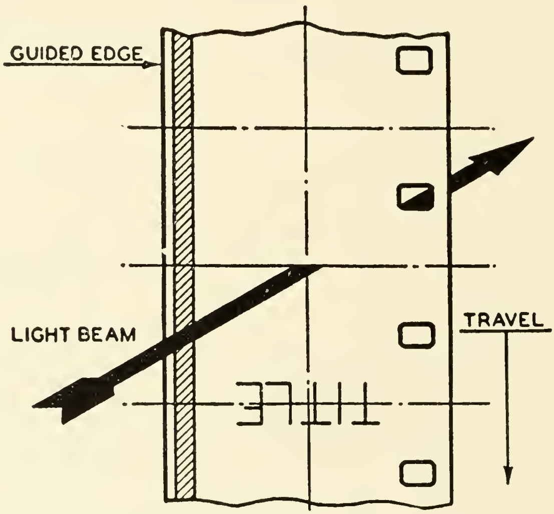
Emulsion Positions of Prints and How They Occur

There is no doubt that matters would be greatly simplified for film users if all 16-mm prints manufactured had but a single emulsion position. Unfortunately this is easier said than done. For the present

American Standard

Emulsion and Sound Record Positions in Projector for Direct Front Projection of 16-Millimeter Sound Motion Picture Film*

ASA
Reg. U. S. Pat. Off.
Z22.16-1947
Revision of
Z22.16-1941



Drawing shows film as seen from the light-source in the projector.

1. Emulsion Position

1.1 The emulsion position in the projector shall be toward the lens, except for special processes.

2. Speed of Projection

2.1 The speed of projection shall be 24 frames per second.

3. Distance Between Picture and Sound

3.1 The distance between the center of the picture and the corresponding sound shall be 26 frames.

Figure 19

there is no simple method of accomplishing this most desirable objective without discriminating in some important manner against certain relatively large groups of film users.

The major difficulty stems from the facts that (*a*) the cheapest and simplest method of picture printing is contact printing, (*b*) with even the best equipment it is not possible to add extra steps in processing without serious losses in picture quality in the release print, and (*c*) although optical release printing of the picture is capable of correcting the emulsion position, suitable printers are very costly, require a great deal of maintenance, and operate at relatively very slow speeds. All this may be summed up simply by saying that it can be done, but someone will have to be prepared to pay the extra costs. It is difficult to convince direct 16-mm film users that optical printing of the picture has great advantages beyond that of emulsion position; their argument is: "If optical release printing of picture is as good as it seems, why is it that not one single major Hollywood studio prints black-and-white 35-mm film in that manner? Certainly Hollywood can afford it if they think it is good." That argument is a difficult one to refute.

Figure 19 is the current ASA emulsion position standard. Figure 20 shows common processes involving 16-mm contact printing that result in prints with the standard emulsion position. Figure 21 shows the common processes involving 16-mm contact printing that result in prints with the nonstandard emulsion position.

A well-planned picture takes into account the emulsion position of the release print and how it is to be obtained quite as much as it does the photographic images to be recorded on the film. For this reason it is wise for persons concerned with distribution especially to familiarize themselves with laboratory operations in order that they will understand the problems and processes in obtaining the best result from a given set of films.

Current Status of 16-Mm with Regard to Emulsion Position

Most 16-mm composite release prints in black-and-white of any origin occur in the standard emulsion position; during World War II standard emulsion position release prints went well over a hundred million feet per year. It seems reasonable to believe that most composite 16-mm color dupe prints have the nonstandard emulsion position; the total output at the present time probably exceeds fifty million feet per year. When it is remembered that the cost of a composite color dupe print is

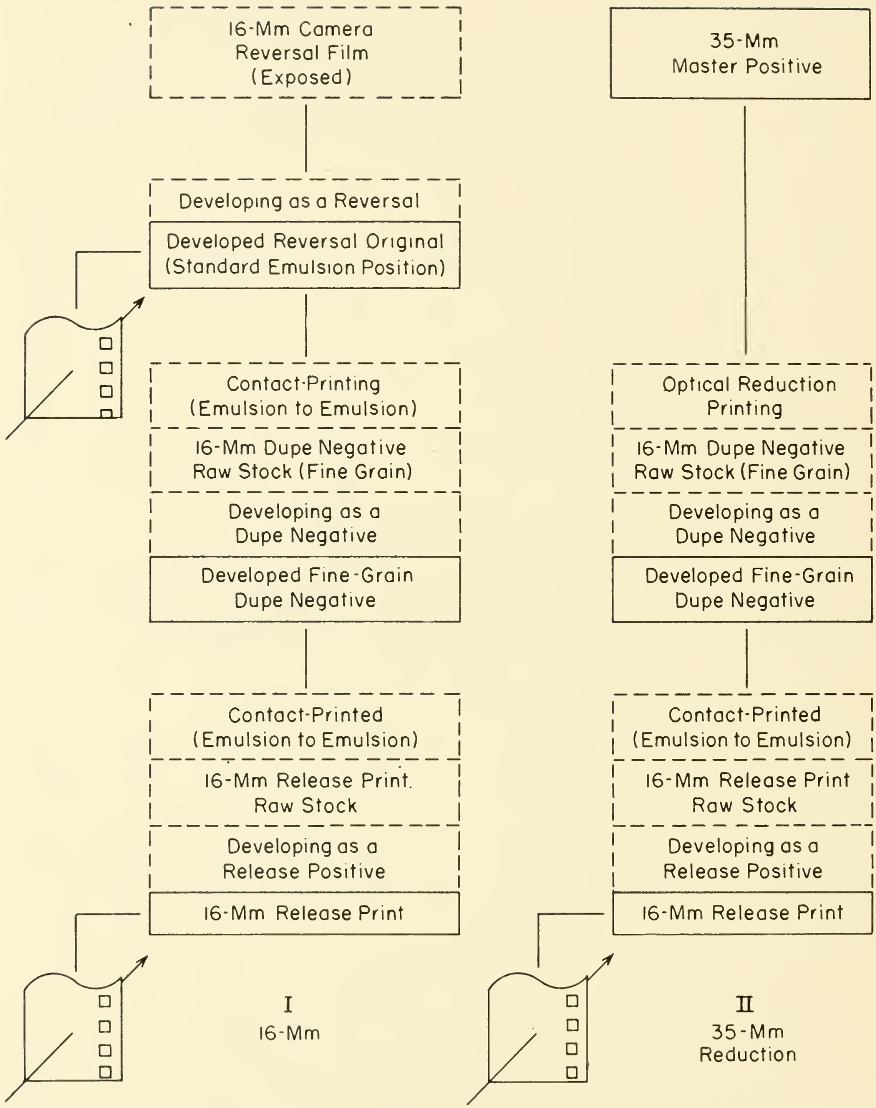


Fig. 20. Process diagram for standard emulsion position prints. In Figures 20 and 21, a solid block represents a developed film.

about $50 whereas the cost of a black-and-white print is about $10, it becomes apparent that the nonstandard emulsion position of second generation color dupe prints is entitled to serious considerations because of the dollar volume involved.

When projecting such color dupe prints, it is found necessary to refocus the picture projection lens to the opposite side of the film (0.006

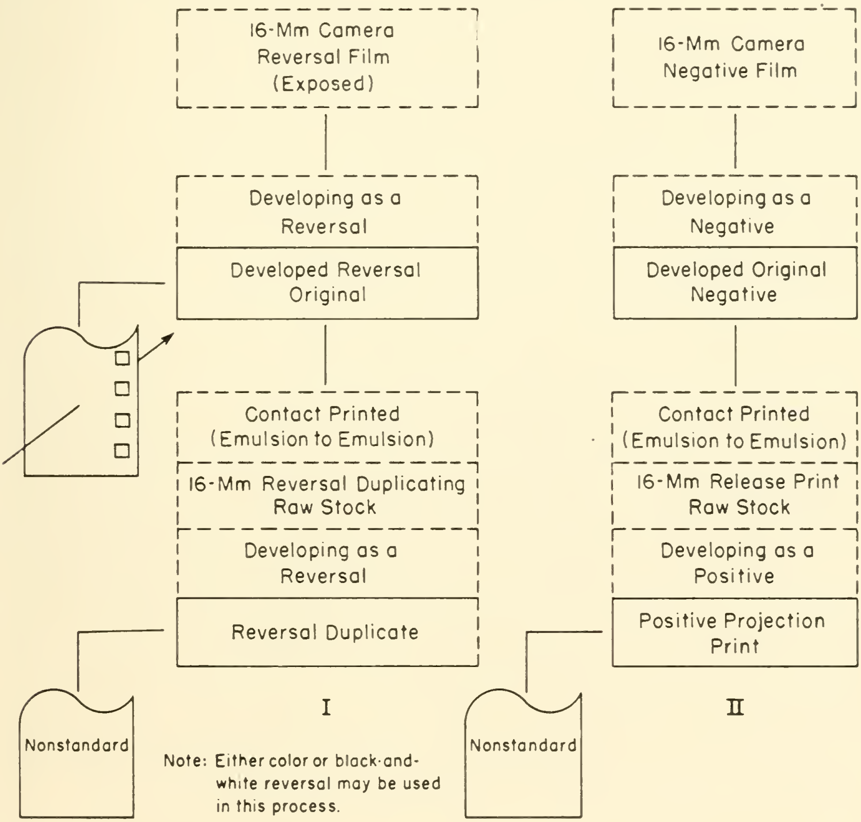


Fig. 21. Process diagram for nonstandard emulsion position prints.

in.) if the picture is to be clearly seen on the screen; the emulsion position is nonstandard. It would seem almost obvious, therefore, that if the picture must be refocused to be clearly seen, the sound optics must likewise be refocused if the sound is to be clearly heard. If good performance is expected from the sound track, every precaution must be observed

to preserve fidelity which is easily degraded by even the slightest relaxing of care and vigilance in sound track focusing. The quality losses in the copying of films are so great that every precaution possible should be exercised to make certain that the images on the film that do appear are accurately translated. Although the maximum resolution of the picture image of a commercial print is rarely greater at the center than 40 lines per millimeter, the American War Standard Specification for the Military Model 16-Mm Sound Motion Picture Projector (issued as JAN-P-49) called for a resolving power of the projection objective lens of 90 lines per millimeter at the center [Par. E-lm (6)]. Since the resolution of the picture as measured on the screen would be reduced to possibly one-half of its maximum value if the emulsion of the film were on one surface and the projection lens were focused on the opposite surface, it is necessary to refocus the picture objective lens to restore the resolving power lost by the incorrect location of the plane of the image. A simple twist of the wrist corrects picture objective focusing by the required 0.006 in.

The surprising feature of 16-mm sound projectors is that they are ordinarily adjusted for standard emulsion position prints only, and it is impracticable if not impossible to refocus, with no interruption in a show, the sound optics for the proper projection of composite color dupe prints made by contact printing directly from an original Kodachrome or AnscoColor picture. Although the large majority of films to be projected by a 16-mm sound projector are black-and-white which require the standard emulsion position, there is a very considerable dollar volume of color prints with nonstandard emulsion position that demand sound refocusing to overcome the inherent disadvantages of the use of the integral layer tri-pack for the sound record without incurring the additional penalty of being out of focus. *With present-day optics, there is no satisfactory compromise fixed adjustment suitable for both emulsion positions.* The usual adjustment is in the form of a small lever associated with the sound optical system; this lever has two definite settings—one for each emulsion position. On any really good film reproduced on any really good machine with really good optics, the shifting of the lever from one position to another will immediately identify the correct emulsion position to any normal listening ear.

Only Eastman Kodak has supplied such an adjustment on certain of their sound projector models as standard equipment. Bell and Howell makes this adjustment available on certain projector models at extra charge. Other manufacturers make no provision at all for the adjust-

ment. The sound optics of most of the latter machines are not among the best on the market.

It should be mentioned that all sound projectors can be adjusted by the manufacturer to project either emulsion position satisfactorily; this is accomplished by merely focusing the sound optics on the desired side. Generally speaking, when no adjustment is provided, the projector is set for standard emulsion position films.

For the present it seems clear that neither emulsion position can be successfully ignored. The dollar value of composite color dupe prints is already sufficiently high in comparison with black-and-white prints to prevent their needs from being ignored. If the higher budget costs of the 16-mm color film is also taken into consideration, it seems an anomaly that projector manufacturers have chosen to concentrate upon the satisfactory reproduction of cheap black-and-white prints and have chosen to penalize the costly color films which really need the best in reproduction that is possible. It should be noted in this connection that due recognition was given to the nonstandard emulsion position in the War Committee on Photography and Cinematography Z52 of the American Standards Association. In the projector specification previously referred to in section E-2c(7): ''Provision for focus of scanning beam—An adjustment shall be provided for focusing the scanning light beam upon either surface of the film. Positive means shall be provided for holding separately the adjustment in each of these 2 positions of focus. . . .''

There are two sides to the emulsion position problem and to the film—and the quality of sound reproduction depends materially on ''which side is up.'' Until some significant changes of widespread magnitude have been completed that eliminate prints with the nonstandard emulsion position from circulation and use, provision for focusing at will of the sound-optical system on either side of the film will remain just as important for the sound track as it does for the picture. For the present, print buyers, being price-conscious, will no doubt continue to purchase contact-prints as the ''best buy for their money.'' Should this be so, it appears that the emulsion position problem will remain with us for a while longer despite the desires of many equipment manufacturers and others to eliminate nonstandard emulsion position prints.

Selected References

Offenhauser, W. H., "Review of the Question of 16-Mm Emulsion Position," JSMPE, 39, 123, (Aug. 1942).

CHAPTER VII

Cameras, Camera Equipment, and Cinematography

Introduction

It has been said that motion pictures are produced by projecting on a screen in rapid succession a series of pictures each of which differs slightly from the preceding one. The screen is dark during the interval required for changing from one frame to the next, but, because of the persistence of vision, the dark interval is not observed. One picture follows another in such rapid succession that the illusion of a single moving picture is produced.

General Functions of a Camera

The prime function of a camera is to place a series of photographed pictures along a roll of film in such manner that the pictures after editing and copying are suitable for projection on a 16-mm silent or sound projector. To accomplish this, the camera must meet a number of important requirements. One of the first requirements is that of proper operating speed. Since the film produced must be suited to projection on a sound projector at a speed of 24 frames per second plus or minus 0.75%, it is obvious that for synchronized sound recording the speed of the camera must have the same nominal value. In this event both camera and sound-recording machine must run in accurate synchronism. The camera speed tolerance should be appreciably closer than the projector speed tolerance specified; since suitable cameras are customarily driven by a synchronous motor from the alternating-current central station mains, the speed tolerance need be but little more than that due to the frequency regulation of the power supply. In the case of central station supply in a large city, a tolerance as small as 0.1 cycle in 60 cycles is not uncommon. If synchronized sound is not a problem, and the picture will be scored with sound after editing, the important requirement of camera speed is that it be constant and that the photographing rate be chosen to portray the desired action at the desired rate (as viewed

on the 24-frames-per-second projector). At the chosen photographing rate, the individual pictures along the film should be unmarred by the blurring that occurs in a still picture when the still camera is set for an exposure time of 1/25 second and the subject moves his head suddenly just as the photographer presses the button.

Presentation of a sharp and clear picture with a motion picture camera is the same fundamental problem as with a still camera because the motion picture film is, in one sense, merely a strip with a succession of still pictures photographed upon it. Most 16-mm cameras do not have adjustable shutters; since the customary shutter opening is 170 degrees, the exposure time of most 16-mm cameras is slightly less than one-half of that implied by the camera speed. In the case of a camera photographing at the rate of 24 frames per second, for example, the exposure time per frame is approximately 1/50 sec. For cameras with other shutters, fixed or adjustable, the exposure time may be estimated roughly as:

$$\frac{\text{Degrees opening of shutter}}{360} \times \frac{1}{\text{Frames per second}} = \text{Exposure time (in seconds)}$$

Spring-Driven Cameras

Most of the readily available 16-mm cameras are spring-driven; this includes the various Eastman, Bell and Howell, Victor, DeVry, Zeiss, Stewart Warner, Keystone, Bolex, and others. There is no spring-driven camera on the market that is capable of running even 30 feet of film with one winding of the camera spring (at a speed of 24 frames per second plus or minus 0.5%). Certain of these cameras are suited for motor drive with a synchronous motor; the more important are the Eastman Cine-Kodak Special (Fig. 22) and the Bell and Howell Model 70 DA (Fig. 23). A synchronous motor drive for the Special may be obtained from a number of sources; essentially, the motor used is a single-phase synchronous motor made by Bodine or similar motor manufacturer and adapted by a number of camera equipment manufacturers. The best source of a synchronous motor drive for the Bell and Howell 70 camera is the camera manufacturer.

As a practical matter it is wise to buy a camera that can be motor-driven even though the camera will be used primarily as a spring-driven hand camera. With motor drive readily available, it is possible to check

the operating speed of the camera driven by the spring motor by comparing it with that driven by the synchronous motor. Photographing the sweep second hand of a clock over a length of 50 feet of film, first with the spring drive and then with motor drive, will produce two strips of film that can be compared with one another by running them through a synchronizer (double sprocket film-measuring machine such as a Neumade—see Chap. X). The film speeds and the ''running down'' of the spring can be readily checked by observing the frame number and comparing it with the location of the sweep second hand.

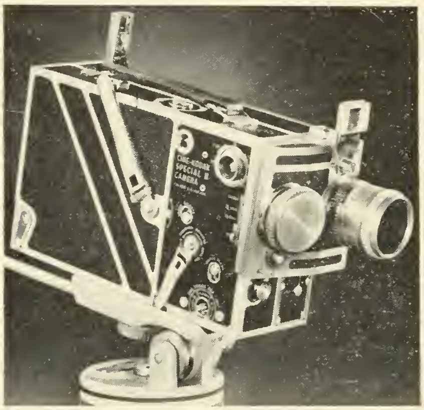


Fig. 22. Eastman Cine-Kodak Special II camera.

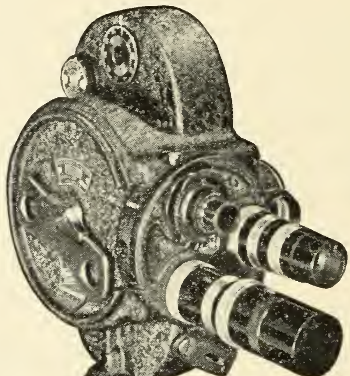


Fig. 23. Bell and Howell 70DA Filmo camera.

There are many shots for which an exactly standardized speed is not required. If a shot is short and, in addition, if there is no need for ''on the nose'' synchronization of sound, spring-driven cameras such as the Bell and Howell and the Eastman Special are quite satisfactory.

Magazine Cameras

A special type of spring-driven camera that deserves mention is the magazine-type camera, although it is not ordinarily suited to motor drive. The main difference between the magazine-type camera and other spring-driven cameras is in loading. The magazine type takes a factory-threaded rectangular-shaped magazine which slips inside the camera. No threading of film in the camera is necessary, since all the threading required is done inside the magazine itself. A magazine camera is loaded by merely opening the camera and pushing the magazine into

place where it automatically finds its correct position with respect to the camera lens, where it automatically permits the safety shutter of the magazine to open when the camera is run, and where it automatically cooperates with the camera drive mechanism.

Since the feed spool and the takeup spool of the camera are located within the magazine, no ''fussing'' is required to use the camera. Magazine-type cameras such as the Eastman ''Magazine Cine-Kodak'' and the Bell and Howell ''Filmo Auto-Load'' (see Fig. 24), ''Auto-Load Speedster,'' and ''Auto-Master'' are made in 50-ft. magazine capacity. Standard sound speed is 36 ft. per minute, and a magazine camera therefore holds sufficient film for only 1.5 minutes of filming. With

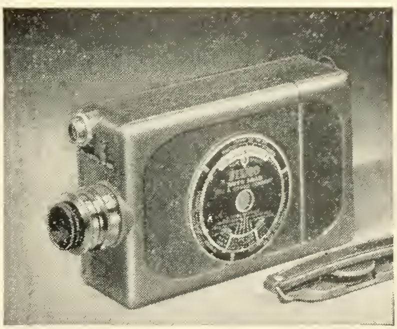


Fig. 24. Bell and Howell Filmo Auto-Load camera.

such a small roll, the camera is practical primarily for cut-in shots and is not really suited to production filming.

With the Eastman Magazine Cine-Kodak it is possible to focus very accurately if the magazine is removed and the reflex viewing microscope that is available is inserted in place. The magnifying eyepiece enlarges the image found on the ground glass that is located in the plane formerly occupied by the emulsion of the film in the camera. Like other reflex finders similarly arranged, it cannot be used during photographing; it must be removed and the magazine inserted in its place, while retaining all existing focusing settings.

Larger Spring-Driven Cameras

The Eastman Cine-Kodak Special is not called a magazine camera, for it is threaded with film mounted on daylight loading spools. The Special is a camera built in two halves; one half is the drive mechanism, and

the other half—which is separable—is called the film chamber. Film chambers are made in two sizes: 100 and 200 ft. The smaller is the same size as the mechanism portion of the camera, the larger is larger than the mechanism portion of the camera. Since the Special is a form of magazine camera, the pull-down claw for the film is located in the film chamber. This is a disadvantage because the photographed frame line shifts appreciably due to film shrinkage; the amount of shift is dependent upon the percentage of film shrinkage multiplied by the number of frames distance between the photographing aperture and the claw. In older models of this camera the separation of gate and claw was as much as 9 frames; newer cameras have a much smaller separation—about 4 frames. Frame line shift is particularly annoying when magazines are to be interchanged; it is obvious that the magazines have to be "fitted" to the camera to make certain that the claw arrangement makes satisfactory allowance for the distance between gate and claw in the particular camera at hand. Kodak is prepared to fit the chambers.

Eastman lenses (16-mm) are not equipped with the "Type C" lens mount employed by most all other manufacturers; they use a special bayonet type of mount found in Eastman cameras only. In general, the Eastman lenses are among the best on the 16-mm market; to use them on other cameras requires an Eastman adapter that reconciles the bayonet Eastman mount and the customary Type C mount.

It should not be assumed that the film plane taken by the film at all the various speeds possible with the Special is identical; most factory adjustments and tests are customarily made at the common speeds, such as 16 or 24 frames per second. At higher speeds (such as 64 frames per second), the location of the actual film plane is somewhat different from its location at the more customary speeds; this is a result of the gate construction. For ordinary purposes, where best image definition is not imperative, this class of gate is considered preferable, since there is less difficulty with film scratches that occur because of dirt picked up by the camera.

The Special is one of the most versatile cameras made. Some of its features are:

(*1*) Adjustable shutter opening with stops at full, $\frac{1}{2}$, $\frac{1}{4}$, and closed. There is a warning buzz when the camera runs with the shutter closed.

(*2*) A number of camera speeds from 8 to 64 frames per second can be obtained from the spring motor. An electric camera motor may be connected to the camera, either synchronous or "wild." (A "wild" motor is a variable-speed motor.)

(*3*) A two-lens turret. (Lenses are Eastman bayonet mount only.)

(*4*) The camera may be hand cranked; one crank is for 8 frames per turn, the other is for one frame per turn. To expose a single frame, it is also possible to use the spring motor by pressing the single frame exposure button; this is useful for time exposures for animation and the like.

(*5*) Each chamber has its own footage meter. The mechanism portion of the camera provides a footage counter and a frame counter.

(*6*) The film may be wound back. Dissolves, etc., may be made by winding back; generally speaking, however, effects should be made in the laboratory and not in the camera.

(*7*) A reflex finder—it is possible with the reflex finder to check focus through the photographing lens as in a still camera of the reflex type. A reflex finder image magnifier which enlarges the image can be used with the 100-ft. film chamber; this magnifier is often desirable, since the image in the regular reflex finder is too small to show the detail to be photographed satisfactorily. Since the reflex finder cannot be used when photographing, an optical finder, which may be set to account for parallax of the different lenses to be used, can be used instead of the regular finder which has parallax error. The optical finder is fitted with a scale for parallax correction at 2, 3, 4, 6, 10, and 100 ft.

(*8*) Attachments for motion photomicrography, and for other specialized motion picture work may be obtained for the Special.

The Bell and Howell Filmo Model 70DA is another of the larger 16-mm spring-driven cameras. The Special is rectangular in shape, the Filmo has rounded top and bottom portions which conform generally to the film spools used. The choice between the Special and the Filmo is primarily one of personal convenience. The Filmo 70-H can accommodate either 200-ft. or 400-ft. magazines; the convenience of the larger magazine is especially appreciated if the camera is motor-driven and if production time delays incurred by changing magazines are extensive. Most of the Filmos of the 70 series (other than the 70-H) take only the 100-ft. daylight loading spool as the maximum.

The Filmo is an excellent hand camera; it is matched in popularity with professional photographers only by its 35-mm hand-held counterpart, the Eyemo. The gate construction of this camera is especially good; it is of the so-called "tight gate" type that has the movement claw located at, or very close to, the aperture and is designed to accommodate a maximum thickness of film of but little more than twice the actual film thickness. For this reason, it will not show the shift in film plane found in the Special at different speeds. It will, on the other hand, cause more serious film scratches if it is not kept scrupulously clean, since "chunks" of foreign matter will become jammed in the gate rather than cause a releasing of the gate spring as in the case of a

Special. It is to be recommended especially if photographing at different speeds with the same camera is required. Some of the features of the Filmo 70DA are:

(*1*) A governor which stops the camera when the spring is run down to a predetermined point. If the spring is not wound sufficiently, the camera will not start.

(*2*) A number of camera speeds is obtainable in about the same range as the Special. Like the Special, an electric motor of either the ''wild'' type or of the synchronous type may be used. The shutter has a maximum opening of 204 degrees.

(*3*) A three-lens turret.

(*4*) There is little occasion to hand-crank a Filmo ordinarily.

(*5*) Daylight loading spools in the standard sizes (50 and 100 ft.) may be used. The B&H 70-H 400-ft. magazines may be intended for film in laboratory packing or they may be of the type intended for daylight spools. If for laboratory packing, adapters can be obtained for adapting the spindles of the magazine from the smaller daylight spool size, to lab packing size.

(*6*) A suitable footage and frame counter is provided.

(*7*) No provision for windback is ordinarily made.

(*8*) The finder which is on the side housing of the camera includes masks to limit the field seen to that of the photographing lens; no parallax correction is provided. A critical focuser is provided for checking focus and lens field; functionally, this is similar to the reflex finder of the Special.

(*9*) Accessories are available for the Filmo but their variety is not as great as that of the Special, since the Filmo is primarily intended to be a good hand-held camera.

Professional Cameras

None of the previously mentioned cameras can be called truly professional because they are not intended primarily for studio use. In particular, their shortcomings are primarily those concerned with convenience in operating expected from a camera intended for studio photographing or location photographing of the conventional kinds. Among the best-known cameras of this latter group are the Maurer Silent Professional 16-mm camera (Fig. 25) and the Mitchell 16-mm camera (Fig. 26). Both were designed primarily as motor-driven cameras and not adaptations of spring-driven designs to motor drive. Both are designed for single-perforated film; obviously, double-perforated film will also run satisfactorily in them. Neither camera is made or intended for single system sound recording, since there are no recording facilities incorporated. (Both manufacturers recognize that the resolving power of camera films is too low and not otherwise suited to variable-area sound recording.) Since both are designed as studio cameras *per se*, their prices are much higher than the spring-driven types; the former are priced in

thousands of dollars, the latter in hundreds. Both are capable of meeting the exacting speed requirement of 24 frames per second ±0.5%; both are of the "tight gate" type which holds the film quite flat in the aperture at any conventional operating speed. Both use detachable camera magazines, the Maurer using a gear-driven magazine and the Mitchell, a belt-driven magazine. Both provide a multi-lens turret.

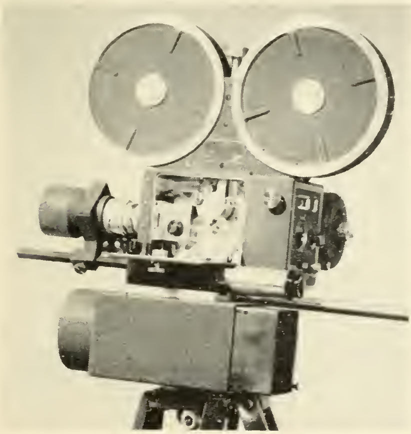


Fig. 25. Maurer 16-mm silent professional camera. Special movement and claw; no registration pin. In the new movement, the claw performs registering function more accurately than a pin, by having the claw stationary for an instant before being withdrawn from the perforation. Camera has 3-lens turret, 235° shutter, and view finder providing erect image $2\frac{1}{4}''$ by $3''$ for both the 15-mm and 25-mm focal length lenses. Camera is racked over for focusing as with Mitchell 35-mm.

Fig. 26. Mitchell 16-mm professional camera. Has the conventional Mitchell movement claw and registration pin movement that has proved so satisfactory in 35-mm Hollywood studios. It also has a 4-lens turret, and a 175° shutter.

The choice between them is primarily one of price and of operating convenience; the performance of both is good, although differing slightly in some particulars.

Choice of a Camera

There is no straightforward answer to the question: "What is the best 16-mm camera?"; the question can only be answered if another

question is asked in response, "What do you wish to photograph with the camera you propose to purchase?"

Several factors must be given consideration in purchasing a camera; it must be remembered that every camera built has been designed as an engineering compromise of a large number of contributing factors, not the least important of which was cost. For the "average" situation, it is likely that neither the cheapest nor the most expensive camera is best suited to the work to be done. It is quite possible that no single camera can accomplish all that is desired; several may be needed to photograph the desired film or films. Should high-speed photography be needed for a desired film, possibly none of the cameras mentioned would be suitable, and it would be necessary to use either a Western Electric high-speed Fastax camera, an Eastman high-speed camera, or even one of the Edgerton flashing-light cameras made by the General Radio Company of Cambridge, Mass.

The Mechanism

A camera is a mechanism for photographing motion pictures, consisting of a film-transport system that moves film: (*a*) from a feed spool; (*b*) to a feed sprocket (which may be a combination sprocket); (*c*) thence by means of a loop to the picture gate where it is propelled by the camera movement; (*d*) thence by means of a second loop to a takeup sprocket (which may be combined with the feed sprocket); and (*e*) finally to a takeup spool.

In the usual cameras, a rotating disc shutter is synchronized with the film movement to admit light from the camera lens to the film while the film is stationary in the film gate; the shutter cuts off the light when the film is being transported past the film gate. The shutter opening may be fixed or adjustable.

Camera Adjuncts

For convenience in operation, a camera has a number of other adjuncts—some essential, some optional. These include:

(*1*) A means of film propulsion—a spring motor, an electric motor, a hand crank.

(*2*) A film housing called a magazine that holds both feed and takeup spools.

(*3*) Some form of film-footage meter, oftentimes measuring in feet and frames, showing how much film remains unused in the camera, and/or how much film has been run through the camera.

(*4*) A finder mounted near the optical axis of the camera so that the action being photographed may be watched. (The field covered by the photographing lens should

be similar in shape and size to the field of view in the finder. Parallax correction for the finder should be provided.)

(*5*) A means of optically checking the accuracy of the lens focus setting: this may be in the form of a viewing microscope, a reflex finder, or a critical focuser. (The lower priced cameras are ''blind'' and do not have this feature.)

(*6*) A shift-over mechanism by means of which the main box containing the film transport mechanism and the photographing aperture is moved to one side, placing a second aperture of the same size as the photographing aperture on the lens axis; the lens turret of the camera remains in its original position. This second aperture is provided with a glass reticle cover that carries engraved lines showing the size of the projector aperture which is smaller than the photographing aperture, and, in addition, showing a pair of crossed hair lines locating the exact center of the aperture. These markings are an aid in properly composing the picture within the frame. (This feature is usually found only on higher priced, professional cameras.)

(*7*) A tripod—this is a very rigid three-legged support, adjustable in height, that is made as light as possible consistent with rigidity. Tripods usually have movable heads for panoram and tilt movement of the camera; it may be in the form of a gyroscope-like gear-train control for smooth ''pan'' and tilt movement (called a gyro-head tripod, such as the one made by Akeley*), or it may be in the form of a friction-head arrangement for pan and tilt control as made by most manufacturers. When panning and tilting is important in a picture, the Akeley Gyro tripod is excellent. It has one disadvantage other than its greater bulk and weight; its gear train is too noisy for use in studio photographing with synchronized sound.

Tripods are usually made in two common sizes, the baby tripod and the regular. The difference between the two is in the length of the tripod legs, the baby having legs about one-half the length of the regular. Tripod legs are sometimes available in two different weights; the Akeley Gyro, for example, may be purchased with either the regular legs or the light legs. Regardless of the weight of the tripod, it should be remembered that a tripod is intended to be a very rigid mounting; in general, the greater the focal length of the lens used on the camera, the more rigid the mounting shall be.

(*8*) A lens turret—this is a mounting integral with the camera, capable of accommodating two or more lenses. The Eastman Special has a two-lens turret; the 70DA Filmo has a three-lens turret. A lens turret can save much production time when it is necessary to change from a lens of one focal length to one of another. It is extremely rare that a single lens is sufficient for photographing professional films, since each filming sequence of a script theoretically calls for a sequence of shots of successively longer focal length; first, a shot to ''establish'' the location of the action, next, a medium shot to act as a transition, and last, a closeup to portray the detail of interest and to exclude other detail not directly related to the subject. To photograph sequences, it may be more convenient to move the camera and to change lenses between shots, or to use two or even more cameras. The actual decision ordinarily depends upon the requirements of the script and upon the production shooting schedule. The shots of the average sequence are quite short, and the importance of

* Akeley Camera Co., 175 Varick St., New York, N. Y.

rapid shifting of lenses and of the rapid changing of the finder adjustments to match is therefore especially important when only a single camera is available.

Other Camera Features

Cameras may have a number of other features, important or otherwise, depending upon just what is to be photographed.

(*9*) Provision for numerous speeds: 8, 16, 24, 32, and 64 frames per second. A note of warning should be sounded; many cameras do not provide the 24 frames-per-second speed. 16, 32, and 64 frames per second is a common combination of speeds.

(*10*) Provision for single-frame exposure—either with mechanically controlled exposure time and/or by hand cranking from a one-frame-per-turn camera shaft.

(*11*) Provision of an eight-frames-per-turn shaft.

(*12*) Provision for film wind-back (for producing certain effects in the camera). Either manually adjustable, automatic, or both, shutter aperture arrangements are customarily also available. (In some cases, provision is also made for the insertion of a mask to cut out part of the camera field in order that the film may later be wound back and the unexposed portion of the field then exposed for the purpose of obtaining a desired split-field effect.)

(*13*) Provision for accurately matching the field of the viewfinder and its location to the field of the camera lens in use. (Oftentimes the finder matches the field of view of a single lens and does not match others. In cases where lenses of longer focal length are used, masking the finder field makes an already small viewing field so very small that it is of very little value in observing and following action.) Should the release print be projected, let us say, on a 12-ft. screen, it would be necessary for the cameraman to focus the original picture accurately enough to assure him that the picture, when so projected, will not be even slightly fuzzy or indistinct when viewed by anyone in the audience. This would seem to demand microscopic examination of the focus adjustment of the camera by some means, such as a viewing microscope, in addition to providing a viewfinder image of sufficiently large size for good and accurate composition.

Design of Cameras

It should be obvious that a camera should leave no scratch marks on a film that has been run through it for photographing. Most of the better-grade cameras are provided with an aperture plate of ground and very highly polished stainless steel, others use a very smooth and highly polished chromium plating over the support metal of which the aperture plate is made. All points in the film paths where the film touches a part of the camera mechanism are highly polished, in order to avoid any possibility of scratching the image-carrying areas of the film. Generally speaking, aperture plates, guides, sprockets, rollers, and other parts of the film transport mechanism are relieved so that no part of the image area of the film comes into physical contact with the camera

mechanism. With such care in manufacture, and with a camera in good condition, the major source of scratch marks is dust, dirt, and metal chips. A camera cannot give truly satisfactory service unless it is kept microscopically clean. Since fine dust is bound to find its way into the camera, it is most essential that the camera be cleaned regularly. The camera manufacturer will provide detailed instructions on what to do and how to do it if the customer will ask him.

Aperture Plate

The camera aperture plate is that plate within a camera against which the film rides to establish accurately the plane of the film with respect to the photographing objective lens. If the camera aperture plate is very accurately made, very smooth, and properly aligned with respect to a well-designed and accurately made camera claw or movement and with respect to the camera lens mount, there should be no difficulty with it. A pressure plate is required to press the film firmly but gently against the camera aperture plate; this too must be very accurately made, very smooth, and properly aligned. The cost of a camera depends to a degree upon the costs of the aperture plate and the pressure plate; some manufacturers make these plates by stamping, then polishing and chromium plating; other manufacturers make them from a solid bar of stainless steel. What is really important is how accurately the pressure plate controls the position of the film, and how free the film is from scratch marks after it has passed through the camera. In most cameras, the aperture plate may be removed readily for cleaning and inspection. It should be needless to remark that the camera must provide the standard aperture. (See ASA—Z22.7.)

*Lens Mount**

The lens mount should preferably accommodate the standard "Type C" lens. This mount has a mounting thread 1.000 in. in diameter and a registration distance of 0.690 ± 0.001 in. or better. The registration distance is the distance along the optical axis from the plane of the seat for the lens mount to the plane of the film emulsion at the center of the aperture. It will be found that many cameras do not have the standard registration distance; some cameras that have the standard registration distance at one speed setting of the camera do not have it at other speed settings. It is well to obtain from the camera manufacturer either a guarantee

* ASA—Z22.76 is the pertinent standard.

that the camera purchased meets this standard requirement, or to have the camera manufacturer modify the camera to meet it. Certain designs of camera gate, particularly those in which the film is not strictly limited by the pressure plate in its movement along the optical axis, can hardly be expected to meet the standard requirement. Since a really good fitting of the lenses to the lens mount requires a total variation of lens and lens mount of 0.001 in. or less, it is usually necessary for a camera manufacturer to match the turret holes for the lenses quite accurately (to better than 0.0005 in.) and to hold all lenses within comparable limits. Lenses purchased at random in the open market may be in error by as much as 0.007 in. The registration distance for every lens to be used must therefore be measured before its distance calibration can be trusted; this is best done by the camera manufacturer. The importance of accurate measurement and fitting will be particularly appreciated if lenses are to be used interchangeably in the various holes in the turret of one camera, and are also to be used interchangeably on other cameras.

Camera Movement

The camera movement is a combination of a film-propelling and a film-registering means. Some cameras such as the Mitchell Pro 16 have a claw for propulsion and a cooperating registration pin for registering; other cameras such as the Maurer 16 Silent Professional rely upon a claw that fits the perforation accurately and that enters the perforation and leaves it in an angular direction accurately normal (perpendicular) to the plane of the film. Although the latter form of construction would probably have been impracticable some ten years ago, the great improvement in dimensional stability of present-day films makes such an arrangement advantageous, since the "dwell" time of the film just prior to exposure may be increased to allow the film to regain the flatness that is lost as a result of rapid deceleration as it approaches the gate prior to exposure.

There are so many interrelated variables involved in the moving of a piece of film in a camera that it it almost impossible to make an unequivocal statement concerning the relative desirability of one type of camera movement with respect to another. A camera with a 180-degree shutter and a short movement time may provide a much sharper picture than the same camera with a 240-degree shutter; during the additional 60 degrees, it is conceivable that the film is "bouncing around" prior to

coming to rest in the aperture and is therefore neither stationary nor flat during a considerable portion of the exposure interval. The theoretical optimum in a film movement is one which moves the film very quickly and then permits almost immediate exposure of the film with the same order of flatness and absence of motion that is found in the finest still cameras. Because of the "bouncing around" referred to, it is quite conceivable that a camera with a somewhat longer movement time may be better than one with a shorter movement time. There is only one criterion—what kind of pictures does the camera take?

Many low-priced cameras use a claw to perform the functions of moving and registering; cameras such as the Eastman Model E do rather well considering the simplicity of construction. Others with more costly parts but with poorer design are not as satisfactory from the performance standpoint. Registration accuracy with respect to the location of the perforations cannot be expected to be as good in poor cameras as it is in cameras such as the Bell and Howell Filmo, the Mitchell, or Maurer cameras.

It is desirable that frame-line shift from the nominal due to all causes shall not exceed 0.003 in., and that frame-line "jiggle" (unsteadiness of the picture due to the differences in frame-line location from one frame to the next) be less than 0.001 in. With really good movements, these errors may be reduced to one-half and even less. Fortunately, Kodak film particularly is quite stable dimensionally, and, in addition, is accurately perforated. If unsteadiness of a photographed picture occurs, the reason is usually to be found elsewhere than in the film.

Camera Lens and the Photographed Frame

The problem of exacting control of the location of all points within the frame being photographed with respect to the "ideal" flat plane is a problem little appreciated by camera users—unless their pictures seem out of focus in one portion of the frame and are in focus at another portion. Ordinarily, it is not possible to place a mechanical supporting member at the back of the film at the center of the aperture—and, unfortunately, the designer is "up against it" because it is an axiom of mechanical design that a flat plate is the weakest possible mechanical section. To add to the complexities of the design problem, the film has a tendency to curl. The base and the emulsion of a film act as the two metals of a bimetallic strip, the emulsion having a much larger expansion coefficient than the base. The amount of curl changes with

the film shrinkage; for this reason best pictures are taken on film that has shrunk least and is the flattest.

Unfortunately, even if film were kept perfectly flat, many pictures would still be in focus in one portion of the frame and out of focus in another portion. In the case of a simple single lens, such as that used on the simplest box cameras, lens field curvature is present; to provide a satisfactorily sharp image over the entire picture area, the film is placed at the distance for best "average" focus and a small relative aperture is used to increase definition and depth of focus. In indoor photographing on Kodachrome with a 16-mm motion picture camera however, it is inconvenient and impracticable to provide the amount of light required for photographing with such a simple lens even should one be available. It is the purpose of a good lens to operate at relatively large openings, and at the same time to exhibit a minimum of aberrations such as spherical aberration, coma, astigmatism, field curvature, distortion, chromatic aberration, or lateral color. Flatness of field (absence of field curvature) is one feature to be expected of every lens sold as a good lens.

Some designers have sought to "match" the curvature of the lens used to the curl of the film in the camera gate. This procedure has not been successful in the main because of the variation in film shrinkage and the consequent uncontrollable variation in curl. It would seem that a good design procedure is to make a film gate to hold the film as flat as possible (taking advantage of the film curl to stiffen the film somewhat and to control its location at the center of the aperture more accurately) and to use lenses with as flat a field as possible.

Lenses themselves do not provide the same definition at all iris diaphragm settings. A good lens (one with good resolving power all over the field) may show a slight improvement of definition at the center when stopped down 1 light stop (*e.g.*, from $f/1.8$ to $f/2.6$). For good modern lenses, the limitation is in the film and not in the lens. It should be remarked at this point that the physical appearance of a lens mount has no bearing on lens quality; lens quality is best determined by bench testing and actual photographing.

Good test charts suitable for lens testing are supplied with the National Bureau of Standards Circular C428 "A Test of Lens Resolution for the Photographer." This is obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 40 cents.

As has been stated before, lens coating can improve a good lens

measurably, but it cannot make up for the defects of a poor one. Since lenses of shorter focal length require a larger number of elements for a good design than do lenses of long focal lengths, aberrations are more likely to be noticeable in lenses of 15-mm and 25-mm focal lengths than in 100-mm and larger focal lengths. It should be noted, incidentally, that the difference between the lens "*f*" rating and its actual light transmission "*t*" will be considerably greater in the lenses of short focal length.

In the long run, it will be found an economy to use only the best lenses available. It is good practice to ask the camera manufacturer to provide you with the data that he has obtained in testing the lenses that he is to adjust to standard registration distance and to fit to your camera. In certain sizes (such as the 2-in. focal length) there are few 16-mm lenses of large opening with small aberrations; one manufacturer in the past has used an Ektar (Eastman) lens intended for the Ektra camera and fitted it with a "Type C" mount. The result was quite satisfying. Although there are now a number of good lenses on the market, some ingenuity is still needed to obtain a set of excellent lenses for 16-mm cameras, particularly in the shorter focal lengths. Unfortunately, it is impossible for a prospective purchaser to select a lens for his particular purpose without making resolving power and similar bench and photographing tests on the particular lens offered for sale. Manufacturers do not provide bench-test data with a lens offered for sale; their brochures and advertising deal too often in glittering superlatives coined by the advertising departments rather than in numerical data provided by the engineering departments. The only protection that a professional photographer can enjoy under such marketing conditions is to buy every lens subject to test approval with the clear-cut understanding that the lens can be returned for credit (preferably full credit) if it is found unsatisfactory within a stated period.

Focusing and Viewing Arrangements

Manufacturers of cameras have vied with one another to provide the best possible focusing and viewing arrangements; yet, with all their efforts, there is no camera that can be considered ideal. Even in the most expensive cameras such as the Mitchell and the Maurer, there is much left to be desired. Coupled view finders of the kind common in pre-war German still cameras of the twin-lens reflex type are still unknown in 16-mm motion picture cameras; in certain quarters, it is con-

sidered doubtful whether the advantages of such construction would be sufficiently worthwhile to enough people to justify the design expense and the probable complexity, particularly for cameras using lenses of different focal lengths.

Although the manufacturers of the better-grade cameras can justifiably boast about the provisions for accurate picture composition and focusing, and about the small amount of parallax error and the brightness of the erecting-prism-type view finders, and how well the finder matches the fields of certain selected lenses, none will say that his arrangement is "the last word" and that the problem needs no further study. The importance of good viewing and focusing arrangements can hardly be overemphasized, and even the best arrangements available today are not as convenient and accurate as is possible. The best procedure in choosing a camera is to examine all cameras commercially available and compare them for the intended purpose. It should not be long before still newer solutions to the focusing and viewing problem will appear in 16-mm motion picture cameras; good solutions will demand a great deal of ingenuity on the part of the designers.

Camera Feed and Takeup Arrangements

If daylight spools are used in a camera, the takeup arrangement can be quite simple, utilizing the usual spring belt for camera takeup drive. In properly designed arrangements of this kind the spring belt is quite satisfactory; it appears to function quite well if the inertia of the film on the takeup spool is relatively low and if the maximum ratio of outside diameter of the film on the takeup spool to the inside diameter is not large. Both 50- and 100-ft. daylight spools have an inside diameter of 1.5 in.; the outside diameter of a 50-ft. spool is 2 13/16 in., the outside diameter of a 100-ft. spool is $3\frac{5}{8}$ in. In the case of a camera using film mounted on a core, the inside diameter of the film is only 1.969 in., while the outside diameter of a 400-ft. roll would be approximately $6\frac{1}{8}$ in. and the outside diameter of 1200-ft. roll would be approximately $10\frac{3}{4}$ in. In the case of both the 400-ft. roll and the 1200-ft. roll, core mounted, the inertia of the film becomes quite large and the ratio of outside diameter to inside diameter becomes quite large, especially in the case of the 1200-ft. roll. Maurer, in providing a 1200-ft. magazine, does not rely upon a spring belt to provide the necessary clutch action required for the takeup, but uses instead a gear-driven magazine driven by a clutch. All Maurer

equipment—camera, sound recorders, and film phonographs—uses gear-driven takeups driven through a clutch.

Regardless of design, a camera takeup should provide a smooth, compact roll of film in the takeup side of the magazine, free of cinch marks due to the slipping of one layer of film upon another that is caused by excessive takeup tension. The roll of film in the takeup side of the magazine should be just as smooth and free from cinch marks and scratches throughout the length of the roll as it is at either end. This has been well provided for in all the better-grade cameras.

Conclusion

As in any manufactured product, the final design of a particular camera chosen by its designer is the result of numerous compromises. Performance requirements are dictated by the intended conditions of use; since many design features of a camera are mutually contradictory in their design requirements, no camera regardless of its price can be considered theoretically ideal for all photographing applications. The practical problem of selecting a camera, therefore, resolves itself into the selection of that particular camera whose intended conditions of use most closely approximate the needs of the intended user.

The camera to be chosen must depend upon what is to be photographed; in every case the choice will involve a compromise in which certain features be sacrificed—internationally or otherwise—for the sake of others. In the beginning, before the requirements become fully known, it is a good rule not to buy the most expensive equipment available, but, rather, equipment of moderate price that will find a ready resale market. Good lenses can be used with any camera if the mounts are of the right kind. When purchasing, it may be a good idea to inquire what the trade in value of the camera may be one year after the date of purchase. If it is found that the camera first chosen is not best for the intended purpose, it may be traded in, and a camera better suited to the intended application may be purchased. It is often difficult to determine just what a particular camera will do and what it will not do, without actually using it for its intended purpose.

One feature for which this is true is the noise produced by the camera when it is running. All cameras make noise when running; for many uses the noise may be of little or no importance. If the camera is to be operated simultaneously with a sound recorder for synchronized dialogue, the noise made by the camera is very important, particularly if the scene

to be recorded requires soft voices or whispering. There is a standard method of measuring the noise level of cameras; it is American Standard (War) Z52.60–1945. Progressive camera manufacturers can and should provide noise level data especially if the camera concerned is intended for simultaneous synchronous sound recording. Such noise data should be available for the camera when used without a blimp; comparative noise data should also be available for the same camera used with typical approved blimps. A blimp (a housing for silencing a camera by enclosing it) may be quite satisfactory with some cameras; with others it may be a nuisance and quite undesirable because it is clumsy and interferes with the camera focusing and viewing arrangements to such an extent as to defeat the designer's purpose in providing them. It may be well to put up with a blimp because it is needed but rarely, and does accomplish the degree of noise reduction desired. In the case of the Eastman Cine Kodak Special, for example, there are several different designs of blimps available; all interfere in some important degree with the focusing and viewing arrangements of the camera proper. In some, the acoustical design is very poor; it represents little more than a box of arbitrary size lined with some arbitrary material. In others, the acoustical design may be fair, but little thought was given to the location and functioning of the camera controls. The usefulness of a particular blimp for a particular camera is best determined by trial under actual conditions of application. The acoustical effectiveness of a blimp can be determined with the method of ASA—Z52.60.

Synchronization of Picture with Sound

There are two methods in use in theatrical 35-mm and in 16-mm motion pictures for recording sound-on-film in synchronism with motion pictures: the "single system," in which picture and sound are recorded upon the film used for taking the picture, and the "double system," in which picture and sound are recorded upon two separate films. The single system of recording is used mostly in connection with newsreel production and is never used for feature production; the double system is used occasionally for newsreel production and always used in connection with feature picture production.

Single System

Single-system equipment has been used to a limited extent for 16-mm. but the sound quality available is so inconsistent and so poor compared

with the quality from double-system sound recording that it is doubtful that the total sound footage of single-system 16-mm professional sound is as great as a small fraction of one per cent. On some occasions when double-system recording is inconvenient because the equipment is too bulky, single-system sound may be recorded. Customarily, however, such sound is re-recorded so that is appears in the same kind of separate film as the remainder of the sound record for the picture, which is almost invariably recorded by the double-system method. When the sound is so re-recorded, it is possible to edit the original picture in just the same manner as the remainder of the picture original, with no regard for the original sound track that happens to be along the unperforated edge of the original film.

Double System

The double system is used in 16-mm wherever it is desired to have the best sound quality practicable in the release print. Because double-system picture and sound are on separate films, each can be given the most appropriate photographic treatment, and each can be edited conveniently without affecting the other. Words and even syllables or objectionable noises can be removed from the sound track without affecting the continuity of the picture.

In double-system recording, the sound track is recorded on the comparatively slow single-perforated, positive-type, sound-recording film. This film is not very light-sensitive when compared with Kodachrome, and is far superior in resolving power. Not the least of its advantages is that its cost is near 1¢ per foot, while Kodachrome costs about 9¢ per foot.

Most 16-mm double-system recording equipment is equipped with synchronous motors for operation from a conventional single phase power line; Maurer equipment can be operated from a conventional 115-v., 60-cycle, single-phase, a.-c. central station lighting circuit. There are performance advantages to three-phase synchronous motor operation, but the relative convenience of the ordinary lighting circuit usually weighs heavily in the choice of equipment for the single-phase supply. All that is necessary is a similar synchronous motor drive for the camera as mentioned in Chapter II.

If a scene is to be photographed with simultaneous synchronized picture and sound, it is only necessary to start both machines, and when they reach synchronous speed (within 2 or 3 seconds after starting), to provide some form of synchronization mark. This is often accomplished

by clapping together once a pair of hinged sticks, called clap sticks. The scene can be set for synchronism by matching up the picture frame showing the meeting of the sticks with the sound track at the point where the noise of the sticks is recorded. With synchronous motors, the scene is in correct synchronism from that point onward.

Another synchronizing method is to flash bloop lights. A bloop light is a small lamp located within a camera or a sound-recording machine that exposes the film on the outside of the sprocket holes when the bloop light button is momentarily pressed. The sound film and the camera film are then matched up as with clap stick marks.

If sound is "post recorded" or "scored," there is no need to run the camera simultaneously with the sound recorder. "Post recording" is the adding of sound after the picture has been photographed, processed, and edited. Sound for this purpose usually takes the form of a speech commentary that explains or is otherwise related to the action portrayed; such sound may include effects or music if appropriate to the subject matter of the film.

Sound is recorded photographically; although there are other methods of recording sound with good quality, photographic recording and reproducing will no doubt continue to be the primary source of sound for composite 16-mm release prints.

Post-recorded sound is usually prepared from a sound script. After the picture has been edited into its final form, a detailed shot list is prepared; this is merely a list that shows the footage and frames reading of a footage counter from the start of the picture to the start of each scene, together with a description of the scene (see Chapter X). With information concerning the subject matter and this shot list, a sound script is prepared, with time cues indicating exactly when the first word describing each scene is to be spoken. With such a script, scoring can then be accomplished by reading the script, cueing each sentence or paragraph with a stop watch.

Cinematography

In the broad sense, cinematography may be said to include not only the mere placing of an image upon the film in the best possible physical manner, but also with the best possible composition, lighting, movement of the subjects within the film frame, and with the best possible relationships between the subject matter to be photographed and the manner of

its presentation on the screen for the intended audience. This subject is too vast to be discussed adequately in anything less than a separate book.

To photograph a scene properly requires an adequate knowledge of the theory of art and film. The literature is quite extensive in the former and much can be found in books, papers, and periodicals concerning the static representation of things and events in pictures. Unfortunately, the literature is not extensive concerning the dynamic representation of things and events.

One of the finest books on the subject is *Film Technique* by Pudovkin; this was translated by Ivor Montagu in England and published by Gollancz of London a decade ago. Although the book was originally written before sound was introduced into films, the text is profound in spite of its somewhat ''ethereal'' theoretical approach.

A report worthy of detailed study is that of the Luchaire Committee on Intellectual Cooperation of the League of Nations written in 1924. The teachings of this report are clear and straightforward.

During World War II a number of papers were published in the *Journal of the Society of Motion Picture Engineers* written by various authors in the Training Film Division, Bureau of Aeronautics, U. S. Navy. These are among the finest published to date in the field of training films, and ''tie down'' in practical form the theoretical concepts of Pudovkin and others, in addition to providing a very big push forward to the theoretical and practical frontiers of training film production that are ordinarily so slow-moving.

For those interested in the broader aspects of the film, one of the finest publications is *The Film in National Life* published in London in 1932 by Allen and Unwin Ltd. at a price of 1 shilling. This publication is a report of a commission on the cultural and educational aspects of all films, entertainment and educational; the report was financed by the Carnegie UK Trust. The several appendices are especially valuable, since they summarize the organization and control of the various film services in the major nations of the world.

There is still a great deal of room for books dealing with the translation, so to speak, of concepts into actual strips of edited film. The entertainment film industry of America has applied these principles very effectively in the production of Hollywood films, but many of the principles are considered trade secrets. The need for production guide books for educational, industrial, and similar films is now very acute, and the vacuum needs to be filled very soon.

Selected References

For bibliographic material the reader is referred to the following indexes to the *Journal of the Society of Motion Picture Engineers.*

July 1916–June 1930

January 1930–December 1933

1936–1945

CHAPTER VIII

Sound, Sound Recording, and Sound-Recording Characteristics

Introduction

Sound may be recorded upon a large number of different media, such as films, disks, cylinders, wires, and even on magnetic iron dust that is coated upon the surface of a strip of filmlike material 16-mm wide and perforated like motion picture film. Only photographic recording will be discussed in this chapter. Although other media may find wide application in making original recordings and for purposes other than the association with pictures in a sound film, such media will be compelled to show markedly superior performance at appreciably lower cost before they will become serious competitors to the photographic recording and reproduction of 16-mm sound in release prints.

Although this book will deal almost entirely with photographic recording and reproduction, some mention must be made of magnetic tape and recording and the strides it is making in attempting to establish a place for itself in the production of sound films. As the cost of release printing must be kept low, it seems doubtful that photographic release printing of sound will be displaced by some other foreseeable copying method in the near future. In the making of the original record, however, the same condition does not hold and it is conceivable that magnetic tape recording may displace photographic recording because of quality superiority and lower operating costs. In the present stage, experimental magnetic tape records running at the same linear speed as the commercial 35-mm photographic record show measurably lower distortion and better signal-to-noise ratio. Recording machines have been modified to run either photographic or magnetic records. As there is almost invariably a re-recording step between the edited original and the release negative, it makes little difference functionally whether the synchronized original is made by photographic or other means if the distortion of the recording is a minimum and the signal-to-noise ratio a maximum. Should the operating reliability of magnetic recorders prove of the same high order

as commercial disk and high-quality film recording machines, magnetic recording on tape has a good chance of displacing photographic recording in the making of original records. Such magnetic tape records may be played back immediately, and there is the saving of the cost of photographic development of the original. Many of the features of magnetic recording and its relation to the making of original recordings will be found in a series of papers in the Jan., 1947 (Vol. 48) issue of the *JSMPE.*

Sound is recorded lengthwise along the film; the distance along the film that represents a wave length for a particular frequency can be calculated readily from the film speed—36 ft. per min. It will be assumed in the figures shown in the table that the film is unshrunk; the distance between the centers of adjacent film perforations will be assumed to be exactly 0.300 in.

In order to determine frequency in a practical case, it is necessary to measure the length along the film of a single wave, and to correct the measurement by the ratio of the nominal distance between sprocket holes to the measured distance between sprocket holes:

$$\text{wave length (corrected) in.} = \text{wave length (measured) in.} \times \frac{0.300 \text{ in.}}{\text{measured distance}}$$

The frequency is then calculated from the relationship $V = n\lambda$, where $V = 7.2$ in./sec. and λ is the wave length (corrected) in inches.

It is apparent that a film speed of 36 ft. per min. is the equivalent of 7.2 in. per second. A frequency of one cycle per second, therefore, will

TABLE XII

Frequency Versus Film Length[a]

Frequency, cycles per second	Length per cycle, inches	Frequency, cycles per second	Length per cycle, inches
1	7.2000	4,000	0.0018
24	0.3000	5,000	0.00144
50	0.1440	6,000	0.00120
100	0.0720	7,000	0.00103
200	0.0360	10,000	0.00072
500	0.01440	12,000	0.00060
1,000	0.0072	15,000	0.00048
2,000	0.0036	20,000	0.00036
3,000	0.0024		

[a] Standard 16-mm sound speed, 36 ft. per min.

spread out lengthwise a distance of 7.200 in. The lengthwise distance for a single cycle of a tone of any particular frequency is therefore equal to 7.200 in. divided by the frequency. Table XII is convenient as a reference in discussing recording frequency ranges, and serves to make the problems of good sound recording on 16-mm film more apparent. Inspection of the table shows quite clearly that, if sound up to 6000 cycles per second is to be recorded, microscopic accuracy is a "must."

General Nature of the Sound to Be Recorded

To simplify the thought sequence in this chapter, a simple type of recorded sound will be assumed. The assumption is reasonable, since the recorded sound in teaching films and the like often consists merely of a commentary voice. The voice may, on occasion, be accompanied by a background of sound effects, and, if appropriate, music.

Music as often used is not appropriate but rather diverting, reducing the attention potential that the film might otherwise reach.

More complex types of sound, such as re-recorded synchronous dialogue and effects that are common in the Hollywood entertainment films are seldom used in 16-mm films because of their lack of suitability and their high production costs. A detailed discussion of such sound tracks and the manner in which they are produced is outside the scope of this book and should be sought in other references. Apart from the cost, simple sound tracks are much more desirable than complicated ones for teaching and related films. The visual impressions conveyed should on the average supply more than three-fourths of the information found in the film. For this reason a well-timed sound track with fewer words is more effective than a wordy one. Momentary silence provides emphasis in a sound track just as it does in a lecture delivered by a good public speaker.

Fidelity of the Recorded Sound

It may seem trite to state that the desideratum is recorded sound that has optimal fidelity when projected with the picture. This self-evident fact is often lost in the maze of process intricacies in which the film becomes involved before it is projected as a release print in a 16-mm projector for an audience for which the film was made.

It would seem obvious that for a particular film subject there should be little difference in quality, except for wear and tear, between any two release prints—regardless of whether the prints being compared are out

of the first production run or whether the first and, say, the 1000th are being compared. This is readily accomplished with adequate planning and knowledge; Walt Disney has re-issued Fantasia to the theaters several times after intervals of several years. The picture and sound quality is not noticeably deteriorated from what it was the first time it appeared on theater screens some years ago. With reasonable care in preservation of the originals and masters, there would seem to be little reason why Disney should not release Fantasia again and again after suitable time periods. Unfortunately, with most 16-mm subjects and with most nontheatrical 35-mm subjects, it has not been uncommon for two prints of the same subject made at different times to bear little if any relation to one another in sound quality. In many such cases, a glaring lack of planning of the print manufacturing process and its coordination with the requirements of storage, preservation, circulation, and exhibition is all too evident. Too often not only the losses in each transfer step are unknown, but also the number of steps between the edited original film and the particular release print is likewise unknown. As the quality of the final product—the release print—depends upon the quality of the sound original and upon the accumulated quality degradations of *all* steps between the edited original and the release print, it is not surprising that a particular release print is often unsatisfactory when projected upon an unknown specific machine before an audience in an unknown auditorium or viewing space. All of the components of the complete system from the very beginning through the very end affect or degrade the quality of the sound heard by the audience. The over-all characteristics of the complete chain are the characteristics that control the final result; the achievement of any particular characteristic in the system must take into account *all* parts of the system.

Before a discussion of the individual elements of the complete recording system can be undertaken, there must be an evaluation of the desired over-all sytem characteristic. A reasonable starting point is the required frequency range.

General Requirements as to Frequency Range. Hearing Perception

The requirements with regard to frequency range are determined by the perception range of the listeners. It is only in recent years that sufficient data have been collected from which statistical studies could be made to define the response–frequency range for an average listener and

for a critical listener. Data were collected for more than 500,000 persons at the Telephone exhibit at the New York World's Fair in 1939 and 1940. The data were analyzed by Fletcher of the Bell Telephone Laboratories. The results of this analysis and related studies that are significant here are as follows.

At the intensity of 120 db (this is a very high near-pain intensity at the threshold of feeling):

(*1*) The *extreme* range that can be perceived by a person with *very acute* hearing is about 16 to 22,000 cycles per second. Despite this extreme intensity, only about 5% of the population can perceive this range.

(*2*) The *median* range that can be perceived by a person with *average* hearing is about 20 to 15,000 cycles per second at this intensity. Note that this range is shortened at both ends when compared with condition (*1*).

(*3*) The *narrow* range that is perceived by the 5% of the population with the *poorest* hearing is less than 25 to 7,000 cycles per second at this intensity. Note that this range is further shortened at both ends when compared with conditions (*2*) and (*1*).

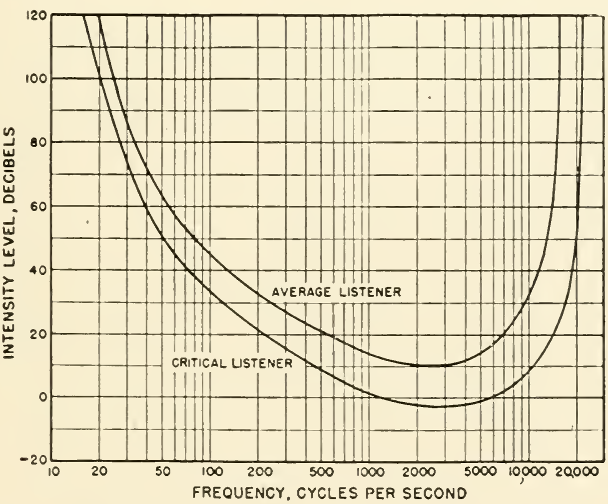


Fig. 27. Hearing contours for average (median population) and critical (5% most acute) listeners in absence of noise.

When the intensity is reduced from the extreme intensity of 120 db to the more customary intensity ranges used in reproducing 16-mm sound films (55 to 75 db), *all three groups suffer a further hearing loss at both ends of the spectrum.* For comparison purposes it may be mentioned that 55 db represents the lowest intensity customarily used in the home with

a radio receiver, while 75 db represents the highest intensity under similar conditions. Figure 27 shows the effect of intensity upon perceived range for music under ideal laboratory conditions (in the absence of noise). These are the hearing contours for an average listener (median population) and for a critical listener (the 5% with most acute hearing) in the absence of noise.

Influence of Noise

Noise is a very variable element in the reproduction of 16-mm sound films. Not only is there an appreciable variation in the amount of recorded noise from one original film to another, and an additional noise variation from one print to another due to processing, but there is also a variation in projection, since the extraneous noise present in the reproduction room is also variable. There are a number of factors that influence the noise present and its masking effect upon the desired sound:

(*1*) The number of people in the audience;

(*2*) The attention which the audience accords the projected film—as measured by the amount of noise that the audience itself produces;

(*3*) The "liveness" of the auditorium or space where the film is projected;

(*4*) The noise level of the sound system (amplifier, photocell, exciter lamp, etc.) of the projector;

(*5*) The noise from the film itself;

(*6*) The noise recorded and printed upon the film; and

(*7*) The noise made by the projector itself.*

In addition to these sources of noise, there are the more obvious sources such as electric fans, street traffic, bells, low-flying aircraft, and even the blaring of nearby radio receivers. In a broad sense, noise may be considered the summation of all acoustic disturbances that tend to mask or otherwise reduce the perception of the desired sound intelligence.

Statistical studies of the masking effect of noise upon reproduction at the noise intensities encountered in homes show a still further shortening of the frequency range at both ends of the spectrum. A very quiet residential noise level is 33 db, while the average residential noise is 43 db. Figure 28 shows the loss in frequency range of the average listener under the 43-db noise condition, and Figure 28A shows the similar loss for the critical listener under the relatively quiet 33-db noise condition.

* One of the most serious sources of noise is the whirring of the high-speed blower used on the conventional projector for lamp cooling. High-speed blowers are small but make much noise; low-speed blowers, while quiet, are large in size.

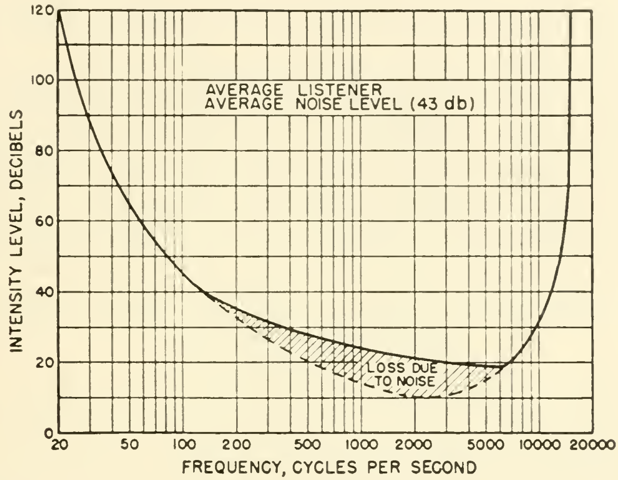


Fig. 28. Effective hearing contour for average listener situated in average noise.

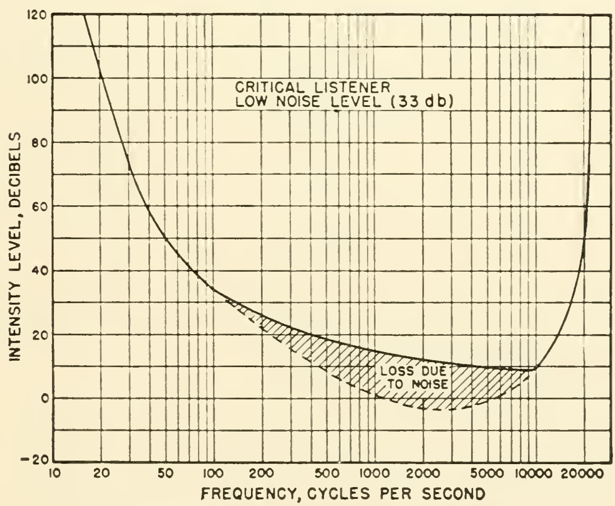


Fig. 28A. Effective hearing contour for critical listener in low noise level.

To provide these data, some 2200 measurements of room noise were made and analyzed by Seacord.*

Up to the present time, measurements on the projection of 16-mm sound films have not been made in sufficient numbers to justify any broad

* Seacord, D. F., "Room Noise at Subscribers' Telephone Locations," *J. Acoust. Soc. Am.*, *12*, 183, July 1940.

conclusions with regard to the noise levels encountered specifically under such conditions.

Certain studies have been made in typical commercial motion picture theaters that suggest the likelihood of rather high noise levels. For practical purposes, therefore, conclusions of reasonable reliability would seem possible if the higher noise level of 43 db is assumed for the purposes of calculation. The assumption has the advantage that many data are available concerning tests, observations, and results at this noise level.

Theoretical Considerations in Speech and Music Reproduction

If a wide frequency range is selected that can be perceived by all persons, it has been found that the just-preceptible cutoffs at the high-frequency end of the spectrum are different for speech than for music. Although this fact has been known for some time, it is only recently that the changes have been numerically evaluated.

TABLE XIII

Table of Liminal Units for Speech and Music

LIM	SPEECH	MUSIC
0	15,000	15,000
−1	7,600	11,000
−2	5,300	8,000
−3	4,400	6,400
−4	3,600	5,300
−5	3,000	4,400

For both speech and music, changes in band width (*i.e.*, frequency range) can be detected up to 15,000 cycles per second. Above 5,000 cycles per second, however, changes in band width for music are twice as readily detectable as for speech. If we consider 15,000 cycles as the upper limit, comparative data may be set forth in tabular form; this is shown in Table XIII. In the figure, the abbreviation LIM may be defined either as: (*a*) the detectable difference in band width that is actually detectable to one-half the observers; or as (*b*) the threshold difference in band width for which there is an even chance of its discernment by a listener. Similar data have not been collected and analyzed for the low-frequency end of the spectrum. For a number of years, however, the empirical relation-

ship of constancy for the arithmetic product of the high-frequency cutoff (in cycles per second), and of the low-frequency cutoff (in cycles per second) has been found to be the most workable relationship to provide a satisfactory "balance." Values for this constant* were as low as 400,000 about 10 years ago, but today's preferred values range between 500,000 and 640,000—with the trend showing preference for the larger figure.

If this constant-product relationship is used to establish the low-frequency cutoff for each high-frequency cutoff, it is then possible to set up a sequential table, listing the ranges so determined. The result can be considered a series of preferred frequency ranges suitable for use in setting the design objectives of practical transmission systems for 16-mm sound film reproduction. Such a series of ranges is shown in Table XIV; these ranges have been grouped into three general arbitrary classifications of high fidelity, medium fidelity, and low fidelity. In this table each music band is separated from the nearest music band by one liminal unit for music, and each speech band is separated from the nearest speech band by

TABLE XIV

Preferred Frequency Ranges

RANGES, (cps)	DESIGNATION		
	GENERAL	MUSIC	SPEECH
	HIGH FIDELITY		
40–15,000	A	1M	1S
65–11,000	B	2M	
75– 8,000	C	3M	
	MEDIUM FIDELITY		
80– 7,600	D		2S
90– 6,400	E	4M	
110– 5,300	F	5M	3S
130– 4,400	G	6M	4S
	LOW FIDELITY		
160– 3,600	H	7M	5S
200– 3,000	I	8M	6S
220– 2,700	J	9M	7S

* It is interesting to note that over 30 years ago, the Research Laboratories of the Western Electric Company (now the Bell Telephone Laboratories) had chosen 800 cps as the "design center" of the audio frequency band. Squaring this value, we obtain 640,000 for the "constant" mentioned.

one liminal unit for speech. For convenience in assessing the performance of 16-mm sound projectors, both tables have been combined into one.

In the high-fidelity ranges, range A is assumed as the complete spectrum. Range B affords as complete perception fidelity for a *critical* listener under the *quietest* noise conditions (for 5% of the population with the most acute hearing at a 33-db noise level). Range C affords as complete perception for an *average* listener under *average* noise conditions (for median population at 43-db noise level).

It is evident from the table, for example, that for a speech-reproducing system with a cutoff of 5300 cycles per second (range $3S$), an extension of the response to 7600 cycles per second (range $2S$) would be required for a change of one liminal unit for speech. If the same system were used only for music reproduction, however, the range would need to be extended a different amount—one liminal unit for music—to provide the just-perceptible difference. The upper limit would then be only 6400 cycles per second (range $4M$). As an extension of the frequency range means increased cost, depending upon the amount of the frequency-range increase, it is important to know whether music or speech, or both, are to be transmitted—if the frequency range desired in a particular case is to be a matter of careful economic selection.

Practical Considerations Affecting the Low-Frequency Cutoff of a System

If the low-frequency cutoff for the next adjacent shorter range is substituted for that of a designated range, it has been found that the "balance" of the reproduced sound does not seem noticeably affected. Thus, in reproducing range F, for example (110–5300 cps), the quality of reproduction and the balance is not noticeably affected *for the average listener* should the cutoff frequency of 130 cps be substituted for the rated cutoff of 110 cps. Since the cost of loudspeakers and of amplifiers designed to cover specified frequency ranges increases fairly rapidly as the low-frequency cutoff is lowered, the increase in cost of the additional low-frequency range is usually distinctly greater than the added subjective result is worth. For this reason, extension of the low-frequency range is rarely justified commercially. As a practical matter, the extension of the low-frequency range below 75 or 80 cps is rarely worth while in any commercial system regardless of the high-frequency cutoff; this is true for

reproduction from 16-mm film quite as much as for other reproduction uses (such as broadcast reception, etc.).

Practical Considerations Concerning Frequency Range and Volume Range of Reproduced Sound*

It must be recognized at the outset that the very wide frequency range and the very wide volume range to which the unaided human ear is responsive is quite beyond the capabilities not only of the best commercial 16-mm films and equipment, but also beyond the capabilities of the best 35-mm commercial theatrical films and equipments. Wide ranges approximating 40 to 15,000 cps in frequency and 60 db in volume range have been demonstrated experimentally with the best possible film-recording techniques; public demonstration of such recording was made in 1940 by the Bell Telephone Laboratories with 35-mm film running at 90 ft. per min. The demonstration equipment incorporated almost every known arrangement for maintaining the widest frequency range and volume range—with minimum noise—with little regard (according to 16-mm standards) to cost and complexity of the equipment involved. The result was outstanding, but the cost of a single demonstration unit was about half a million dollars, putting it far beyond commercial reach for 35-mm as well as 16-mm sound film purposes.

Actual Performance—Past, Present, and Future

For the immediate future, it is hardly reasonable to expect 16-mm performance of the best 5% of projectors and films to go beyond range *F* (110 to 5300 cps) under average noise conditions. Median performance in the near future will probably be in range *G* (130 to 4400 cps) and poor performance in range *H* (160 to 3600 cps). These estimates assume new projectors with new films under improved conditions of machine and film manufacture and use.

At the present time, 16-mm sound film performance occurs almost entirely in the low-fidelity range. The median performance is probably in range *H* (160 to 3600 cps); the performance of the poorest 5% may be as low as range *J* (220 to 2700 cps). On the whole 16-mm performance has not been good; during World War II, for example, some prints de-

*The general conclusions drawn in this chapter are based upon conventional single-channel (monaural) reproducing systems and do not anticipate stereophonic or other binaural systems.

livered by contractors to the Government were so poor that they were unintelligible on any projector. It is doubtful that these could meet even the very low requirements of range *J*. It was such performance of a relatively large number of prints on a relatively large number of projectors that was a prime factor in the formation of the American Standards Association Z52 War Committee on Photography and Cinematography at the joint request of all U.S. Armed Forces in 1943.

Production Implications of Performance Range Requirements

For the sake of eliminating one major variable in the evaluation of film performance, let us assume playback of all sound film upon a single military Model Projector* (Joint Army–Navy Specification JAN-P-49) of average performance as specified. When the specification for this projector was drafted, it was recognized that the highest level of performance commercially feasible was needed for military purposes. Such level of performance is appreciably better than that of any machine commercially marketed up to the time the specification was written. A projector as specified may be considered to have the most desirable design objective performance for a modern 16-mm sound projector.

Despite our assumption of a single machine to eliminate projector variation, large-order variations will be found to occur. As will be pointed out later, variations in performance from one release print to another occur not only for different subjects having different sound originals, but also for different release prints made from a different release master or release negative, for any release prints or other copies made at different times, and even for different release prints made at the same time. It should be apparent that the quality variations are of different orders of magnitude; as in all other cases of manufacture of mass-produced product when quality is statistically in control, the variations among release prints made from the same release master or negative at the same time should be of lowest and minor order of magnitude.

To determine the magnitude of the variation statistically requires measurement in accordance with the methods of statistical quality control (ASA Z1.1, Z1.2, and Z1.3). To know what to do about it requires knowledge and analysis of the process of making the release prints. The very first step prior to an analysis of this kind is to remove from the re-

* A machine of comparable design is being manufactured for the Armed Forces by DeVry of Chicago; another by Bell and Howell.

lease print manufacturing process all unnecessary transfer steps; every transfer step in the manufacturing process introduces a loss of major magnitude. Although statistical quality control is intensively used to measure the quality of motion picture film during manufacture, analysis of even a rudimentary kind in the utilization of the film is the exception rather than the rule. The inevitable result is poor utilization of the quality potential of the raw film.

To predict the performance of a print requires a knowledge of the operating characteristics of each and every step in the production process from the raw material (the raw stock for the original) to the finished product (the release print). Despite this, it is not unusual for a buyer of release prints to have no knowledge whatever of the processes involved in turning out the product he is buying—release prints. Since there are no standards by which the quality of release prints can be accurately measured objectively, the result is no better than a grab-bag filled with items of unpredictable and probably poor quality. It is next to impossible to predict or guarantee performance within specified limits—such as the frequency ranges previously described—without accurate knowledge. Since the processes in 35-mm theatrical films are less varied in type and likewise better stabilized, more data concerning over-all characteristics are available for the large size.

Over-all Characteristics

It should be recognized at the outset that the over-all characteristics of the recording and reproducing system are of paramount importance. We must be concerned with the performance of the particular print that we may be using quite as much as with the performance of the particular sound projector we are using, or, for that matter, of the amplifier used to record the sound original. It is apparent that the recording and reproducing processes as a whole must be designed to anticipate the losses known to exist, and to take into account the tolerances of each of the processes between the time the sound enters the microphone of the recording equipment and the time the reproduced sound issues forth from the loudspeaker of the sound projector. If consistent performance is desired, all factors should be known; if they are not known they should be determined before production recording is attempted.

Distortion

It is unfortunate that no single measurement will define the excellence of sound reproduction or of the degradation of sound reproduction.

Forms of audio distortion are customarily divided into three primary classes: frequency discrimination, tonal distortion consisting of harmonic and amplitude distortion, and phase distortion.

In the past the most advantageous balance among these characteristic forms of distortion has not been maintained; this is the case not only of 16-mm sound, but also of all other forms of sound transmission and sound recording such as broadcast transmission, commercial phonograph recording and reproducing, and the recording and reproducing of electrical transcriptions for broadcast sound transmission.

Frequency Discrimination. Frequency discrimination is the most easily measured of all forms of audio distortion. Although the measurement of the response-frequency characteristics of certain parts of the system (such as the recording amplifier) may be a routine matter, the measurement of the *over-all* response-frequency characteristic is very rare regardless of the purpose of such measurement. Such measurement as a routine quality control measure holds much promise not only as a yardstick for quickly determining whether or not the process remains in control, but is also capable of disclosing quickly when the system has been subjected to major disorders. It is very annoying and costly to find bad sound on a large number of new prints, and to find that the cause is a defective printing master that went by unnoticed because of the absence of a print-through test strip that would have quickly revealed the defect as a part of the routine check of the over-all response-frequency characteristic. Strangely enough, despite the frequency of occurrence of this kind of defect, it is remarkable how often the same error will be made by the same people.

Although frequency discrimination is by no means the only important form of distortion, a routine over-all check will often point out unmistakably just where the process deviated from its intended path. Most of the discussion that follows in this chapter deals with this easily measured characteristic.

Tonal Distortion. Unfortunately, tonal distortion is difficult to measure, since it is not entirely a simple distortion of either the harmonic or amplitude type; it also includes forms of distortion that are emphasized because of the operating peculiarities of the recording method itself. Thus, a primary distortion introduced by improper processing and related causes in the case of variable density sound track is harmonic distortion. To measure and to control this in processing, an intermodulation

test may be made in accordance with American Standard Z22.51-1946 "Method of Making Intermodulation Test on Variable-Density 16-Mm Sound Motion Picture Prints." The tones used for the intermodulation test are 60 cps and 1000 cps.

In the case of variable-area sound track, the major distortion introduced by improper processing is envelope distortion. A somewhat similar testing method called the cross-modulation test is used; different test frequencies have been selected due to the difference in the character of the distortion produced. This test may be made in accordance with American Standard Z22.52-1946 "Method of Making Cross-Modulation Tests on Variable-Area 16-Mm Sound Motion Picture Prints." The test frequencies selected for variable-area testing are 400 cps and 4000 cps.

The data collected on intermodulation distortion tests and on cross-modulation distortion tests for 16-mm prints are too sketchy as yet to establish good correlation with the more customary listening tests, or to determine the relative amounts of subjective distortion when measurements by both methods yield the same numerical values. Such correlations must of necessity be established if we are to continue that desirable practice of altering the form from variable-area to variable-density or *vice versa* by re-recording*—as was very common during World War II. The practice, which has a number of operating advantages, will no doubt become more common in the near future, since Maurer, RCA, and Western Electric market equipment capable of turning out either form. It is also possible that the manufacturers of laboratory sound printers will market machines capable not only of copying the form of the sound track supplied, but also, by the simple shifting of a lever or similar adjustment, to alter the form in printing from variable-area to variable-density and *vice versa*. Such printers have already been described in some detail in patents issued and applied for.

Over-all distortion characteristics do not receive the attention they deserve. Such characteristics often will indicate a strong preference for one particular method of accomplishing a specific result over alternate methods. A typical example would be the re-recording of a negative

* Re-recording presumes a high-quality film phonograph that translates a high-quality print or other sound-positive record into electrical currents suitable for electrically actuating an input channel of a recording equipment (replacing a microphone) for the purpose of obtaining a duplicate sound record, usually modified in response-frequency characteristic, of the high-quality print or record.

from a fine-grain, re-recording positive in preference to making a photographically copied negative from a master positive. Assuming that each is optimally processed for its intended purpose, the distortion present in the print from the re-recorded negative should be of appreciably lower order than that present in the print from the photographically copied duplicate negative. Oftentimes the difference is so large that one method can be termed acceptable and the other unsatisfactory; the result will depend upon the control *actually* exercised rather than upon the nominal control that is theoretically possible in the process. (As a crude example, photographic copying, despite all its shortcomings, would be preferable to a re-recording if a bad microphonic and noisy electron tube were used in the re-recording equipment, especially in the pre-amplifier associated with the film phonograph.)

Phase or Delay Distortion. If a signal of 400 cps is suddenly applied to the microphone of a 16-mm sound recorder, it will be found that there is an appreciable transmission time delay (of the order of a millisecond) between the time that the signal is applied and the time the film is actually exposed by the light beam of the recording machine.

If a signal of 60 cps, for example, is suddenly applied to the same system, it will be found that the transmission time delay is many times its 400-cps value in most 16-mm sound film recording equipment commercially manufactured. If a signal of about 5000 cps is likewise suddenly applied, it will be found that the delay is several times the 400-cps value, but customarily less than its 60-cps value. The variation in transmission time delay in the working frequency range is called phase distortion or delay distortion.

Phase distortion is not limited to electrical circuits; film processing is a source that is usually quite uncontrolled because film laboratories are not generally familiar with electrical measurement methods and rarely if ever attempt to measure the delay distortion or its variations introduced by their processing. Since a delay of a millisecond is roughly the equivalent (in time) of a placement change of the sound source at the microphone of one foot, the importance of large delay differences* between the

* The effect upon the reproduction of a plucked string bass violin in a dance orchestra is a case in point. The frequency range of fundamental and significant overtones is from about 40 to well over 7500 cps. When the sound of such an instrument is recorded and reproduced with equipment of conventional phase distortion characteristics, the low range frequencies and the high range frequencies produced by the instrument are markedly delayed with respect to the mid-range frequencies. In reproduction, this causes a ''confusion'' of sound as the range extremity tones are

low-frequency delay and the high-frequency delay becomes apparent when compared with the 400-cps value. In commercial equipment of reputedly good manufacture, the ratio between the 30-cps value and the 400-cps value may be as high as 20 to 1.

For the present there is very little that can be suggested for the routine measurement and control of phase distortion and for correction of major defects in present-day 16-mm recording systems other than to suggest a more intensive study of the problem by all concerned. In the past, phase distortion and its control has been very important in long-distance telephone transmission where appreciable time delay occurs. Although the maximum transmission time delay for 16-mm recording is but a small fraction of that encountered in a cross-country telephone line, the importance of phase distortion in the high-quality recording and reproduction of 16-mm sound films cannot be ignored, because of the subjective importance of transient and other sounds of sharp attack characteristics. The difference between a high-quality system with low phase distortion and an ordinary system is obvious to even a casual untrained observer when transient sounds such as dancing taps are recorded. Unfortunately there are no simple standard methods available for measuring phase distortion and for correcting it; very little analysis of film processing as a source has been made although it has become more common in recent years for equipment manufacturers to investigate and measure phase distortion in their amplifiers. Much progress should be made toward improving sound recording and reproduction in 16-mm sound-films as a result of the more intensive efforts to analyze and measure phase distortion that will be made in the years to come.

Signal-to-Noise Ratio

The signal-to-noise ratio of a system is another important over-all characteristic. It should be obvious that the best signal-to-noise ratio available is that of the original event being recorded, since each subsequent step in the process *reduces* the signal-to-noise ratio because noise is added. This ratio of the final result (the sound projected into the auditorium from the release print) is usually very much smaller than that of the original event. The noise in the auditorium itself reduces the

---

subjectively localized in space at points distant from the mid-range frequencies; such reproduction with excessive phase shift is quite harsh despite the fact that the measured distortion of the recording and of the reproducing systems may be quite low. (From Offenhauser and Israel, "A Study of the Advantages of Quasi-Binaural Reproduction Systems," 1940, *unpublished*.)

signal-to-noise ratio of the sound emitted by the loudspeakers of the reproducing equipment.

Well-designed equipment is capable of a signal-to-noise ratio of 30 db or more; this is somewhat better than is obtained with the better quality commercial 78-rpm phonograph disk records (shellac pressings) reproduced upon a high-grade electric phonograph in the quiet of a well-furnished living room ((33-db noise level). Most projectors now in use are not capable of reproducing that range; many are reproducing with a signal-to-noise ratio no better than 15-db. Such performance is inferior to a low-priced ($9.00) pre-war midget radio set.

The standard method of measuring signal-to-noise ratio of 16-mm sound motion picture prints is described in American War Standard Z52.38—1945. The reference for this test is a tone of 400 cps recorded at approximately 80% modulation; this reference tone is used for either variable-density or variable-area recording.

Every step in the complete process of recording and reproducing 16-mm sound film is characterized by the noise and by the distortion that it introduces; the aggregate effect is cumulative. An excellent final product results not only from excellent equipment, but also from an applied knowledge of the characteristics of the process that permit the functioning of adjacent steps in complementary (for example, distortion-cancelling) fashion. A typical example is the relation of a conventional variable-density sound negative to its complementary print. Such a negative will seem badly distorted when played back on a conventional reproducer; as is to be expected, this is no surprise to one familiar with the variable-density recording process. The negative itself is neither intended for, nor suited to, playback on conventional equipment; if negative playback is required for any reason, a special type of logarithmic playback amplifier is required. The print, on the other hand, is normal and does not require an unconventional amplifier.

Controlled quality of the release print projected is a result not only of care and constant vigilance in each step of the process, but also of the integration of all steps into a unified whole. A successful process is one in which all transfer characteristics are known and anticipated.

Factors Influencing Response-Frequency Characteristics in 16-Mm Sound Recording

Introduction

In the early stages of the art of 16-mm sound, when films and processing were poor, sound for 16-mm film was often recorded on 33 1/3-rpm

disks and reproduced from a mechanically-coupled reproducing turntable. Sound-on-disk continued to be used for several years after it had disappeared from 35-mm entertainment theaters; it took longer for progress in 16-mm film materials and in 16-mm processing to result in sufficiently improved projection sound quality in the slower-moving 16-mm film to provide commercially satisfactory performance.

The sound-on-film recording method which has superseded sound-on-disk always consists of:

(*1*) A microphone to translate sound energy into electrical energy;

(*2*) An amplifier and associated equipment to amplify the energy from the microphone, and to control the energy supplied to the recording machine;

(*3*) A sound-recording machine (often called a sound recorder) to translate the electrical energy from the amplifier into corresponding light variations that are utilized to expose the continuously moving film and to produce the latent image of the recorded sound on it.

The starting point, of course, is the microphone that first converts sound energy into electrical energy at the recording studio; the end point is the sound projector that translates the light transmitted through the moving photographic image of the release print into electrical energy that is used to drive the reproducing loudspeaker, reconverting the electrical energy back into sound in the auditorium.

Numerous factors affect the manner in which the original recording should be made to assure that the release print is of optimal quality. An acceptable film is almost certain if all factors are properly anticipated; an unsatisfactory film is almost certain if any or all factors are disregarded.

Reproducing *vs.* Recording Level

Sound from 16-mm motion pictures is usually reproduced at a much higher volume level than that of the original event. This is especially true in the case of voice recording; for every difference in level between that of the original sound and that of the reproduced recorded sound, there is an optimal response-frequency characteristic correction that should be applied to the "ideal" flat response-frequency characteristic if the optimal tonal balance is to be maintained.

The correction is primarily an attenuation of the lower frequencies; for large level differences, slight attenuation of the high frequencies is also required. The magnitude of the attenuations is dependent upon the magnitude of the level difference, the customary level difference being about 10 to 20 db. Data have been accumulated by a number of investi-

gators, and essential agreement has been found among the various sets of data.

Fig. 29 shows the average characteristic for recording an average loud male voice so that it will be suitably reproduced on a 16-mm sound projector of conventional design with conventional level difference between the real event and its reproduction. This characteristic assumes a "perfect" recording system, "perfect" processing, and a "perfect" reproducing system. (In this sense, the word "perfect" means an element that introduces no high-frequency or other losses, and likewise introduces no noise and distortion.)

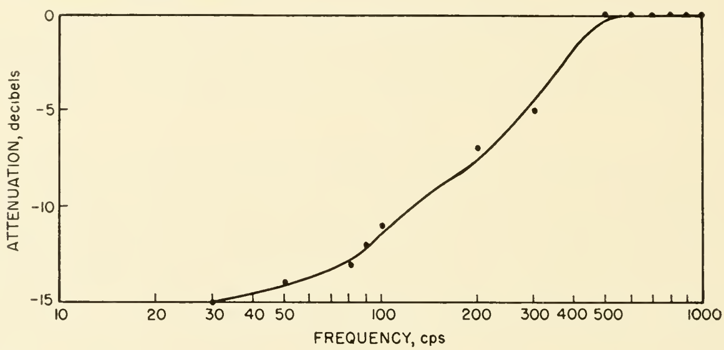


Fig. 29. Average response-frequency characteristic for average loud male voice. Perfect recording system and perfect reproducing system needed to correct for the conventional difference in volume level between the real event and its reproduction on the loudspeaker of a 16-mm sound projector. An equalizer to provide this sort of characteristic for this purpose is called a dialog equalizer.

It should be noted that for music the level of the original event may be quite high, and the level difference between recording and reproducing much smaller than in the case of speech. If music is to be recorded as musical background for a voice, it would even be possible for the level of the orchestra to be lower in reproduction than the level of the original event. It should be quite apparent, therefore, that if musical background is to be used with a voice, the level difference for the voice will be quite different from the level difference for the music. For this reason, a single equalization characteristic will be unsatisfactory for both; individual equalization of the speech and music will be required for optimal quality on the mixed sound track.

Voice Effort

When an average voice is lowered, and the volume control of the recording equipment is advanced to make up for the lowered voice volume,

the recorded voice quality deteriorates because of the predominance of the chest tones in the speaker's voice. Thus, a changed voice effort on the part of an announcer or speaker requires a further correction of the "ideal" flat response-frequency characteristic. In the customary post-recorded film using an off-stage voice, the declamatory voice requires least correction and is usually preferred—especially when there is no psychological or other reason for a different type of voice.

As in the case of level difference correction, the magnitude of the correction required for voice effort depends upon the magnitude of the voice effort difference. Figure 30 shows typical corrections for average voice effort differences of 3, 6, 9, 12, and 15 db.

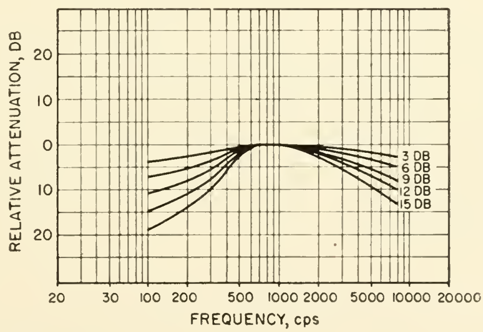


Fig. 30. Dialog equalization corrections required for voice effort differences of 3, 6, 9, 12, and 15 db.

Voice Quality

It should be obvious that all male voices are *not* alike even at the same energy levels. Since "the proof of the pudding is in the eating," the final test is the playback of the release print.

The various corrections described in the preceding sections and in this section are little more than rough approximations of the differences involved. Thus it will be found that the correction required for a particular loud male voice will be slightly different from the average male voice; the precise correction is ordinarily determined by critical listening tests. For recording the particular male voice at a medium level, the correction given in the section on voice effort should make a good first approximation.

If the optimum correction is to be determined for a specific case, it is obtained through critical listening tests and should be found to differ

from the indicated corrections in only minor degree. In making such tests, it cannot be blindly assumed that significant differences do not occur in the projectors used or in the films and their processings. Relatively large differences can and do occur; with regard to films, for example, there are relatively large differences in different emulsion lots of the same type of film; smaller, yet possibly significant roll-to-roll differences occur within the same emulsion lot of film, especially if different rolls have been stored under different storage conditions in the period between manufacture and use. (Storage of raw film is always assumed in unopened taped cans—as supplied by the film manufacturer.)

Since even larger variations are to be expected in the processing of the film, it can be seen that critical listening tests can be of quantitative value only when proper process controls are applied. The responsibility for setting up these controls rests squarely on the shoulders of those making the tests. This requires an appreciation of the performance of film under the different conditions of processing to which it may be subjected, just as much as it implies a good knowledge of the electrical performance of the microphone, amplifiers, sound recording machine, and other electrical components.

Transfer Steps

A transfer step is a step in the process of making sound films in which energy is transferred from one form to another, or images are transferred from one medium to another. It is apparent that there is no "perfect" transfer step; every transfer step results in a transfer loss. A transfer loss ordinarily means a loss of high frequencies, an increase in noise with a consequent reduction in signal-to-noise ratio, and an increase in distortion; the absolute magnitudes of these losses and their relative magnitudes with respect to each other depend upon the character of the transfer step and the manner in which it is actually accomplished. Over-all transfer losses can be kept to a minimum by reducing to the irreducible minimum the number of transfer steps between the original and the release print, and by keeping the losses in each and every transfer step to a minimum. Much can be accomplished in the latter direction by vigilant maintenance of well-designed equipment. Quite often the loss in a particular transfer step is excessive not because the equipment is inadequate for the intended purpose, but rather because the equipment is poorly maintained and not kept at the peak of its operating efficiency.

The result depends upon the control *actually* exercised, and not upon the theoretical limits contemplated in the original design.

The sound that enters the microphone has less distortion and noise than it ever has in any later stage of the process; every subsequent step increases high-frequency loss, noise, and distortion. This applies to the very start of the transfer process—to the microphone itself—quite as much as it does at subsequent steps in the process. The sound actuating the microphone should be as clear as possible and as free of distortion, noise, and unrelated sounds as it is possible to provide. Should there be a quality defect in a commentator's voice such as hoarseness, a wheeze, poor enunciation, poor diction, a whistling noise (such as accompanies sibilants spoken through false teeth), poor breath control, or any other related defect, it is almost certain that the defect will be accentuated by the transfer losses encountered. Under no circumstances should unrelated sounds and noises or other extraneous sounds be present. It should be possible to run a silent portion of the sound track under the quietest auditorium conditions with the best sound projector available and find no sound even when the print is reproduced at the maximum gain setting.

Noise and distortion are added by the equipment; these effects should be small if the equipment is good. High-frequency losses in well-designed amplifier equipment are small; customarily the response-frequency characteristic of the amplifier equipment is intentionally equalized (altered) to compensate not for high-frequency losses inherent in the amplifier, but rather for the high-frequency losses encountered throughout the remainder of the recording and processing procedure. Since equalizing of the electrical amplifier circuits offers the only convenient means for adjusting the over-all response-frequency characteristic of the release print that is run in the projector for the intended audience, the quality of the sound projected with the picture is a measure of how accurately the sound recordist knew the characteristics of the recording and of the processing procedure, and what he did to anticipate its shortcomings and losses. As there is no standardization of procedures and of transfer losses in any step of a procedure, each specific application problem must be studied as an individual case if satisfactory end results are to be obtained.

Noise and distortion are added by the sound-recording machine. Distortion is introduced by the light modulator, and noise by mechanical vibration of the exposure lamp with respect to the optical axis of the recording optical system and by lamp current variations arising from hum and other disturbances in the exposure lamp current supply. A loss of

high frequencies occurs because the light beam pencil that traces the sound waves on the film is not infinitely fine despite its unusual narrowness; the loss is called slit loss. Distortion is also introduced by irregularities in the movement of the film past the exposing light beam; the result is a frequency and amplitude modulation of the recorded sound. Speed variations introduce flutter; slower speed variations are referred to as wows. Fortunately the sum total of distortion and noise introduced in a good recording machine—while noticeable—is not very serious.

The recording film has limited resolving power, and, in developing, both noise and distortion are introduced together with a loss of high frequencies, the latter being called film loss. Film developing also introduces noise; one important source is the dirt and other foreign matter found in all developing and fixing baths. Another important and oftentimes serious source is the dust carried in the drying air in the dry-box of the developing machine.

From this point onward, every step increases noise and distortion as well as losses of high frequencies. Assuming that the original is a sound track negative from which a release print is to be made, the sound printer used will introduce noise, distortion and a loss of high frequencies; the latter is known as printer loss. The raw stock for the release print will introduce more noise and distortion and show a greater loss of high frequencies than the EK Code #5372 film used for making the sound track original. In developing the release print, noise, distortion, and a loss of high frequencies is to be expected once again. Transfer in this manner of the photographic image from the sound track original to the release print is called photographic transfer. Photographic transfer always results in a loss of high frequencies, and in an increase of noise and distortion. A serious increase in distortion can be expected unless considerable effort is expended in choosing the operating parameters of copy exposure and development to minimize the distortion increase by causing the photographic distortion occurring in the print to offset to some degree the distortion occurring in the negative. In the processing of variable-area film this is known as the distortion-cancelling technique.

Should we assume that the original was a direct positive, it would be preferable to re-record the original rather than to print it photographically. Electrical transfer steps such as re-recording are customarily arranged to alter the response-frequency characteristic in a desired manner (usually to offset high-frequency losses occurring in other transfer steps); this equalizing of the response-frequency characteristic is accom-

plished at the cost of an increase in both noise and distortion which is even greater than the increase that would occur if no response-frequency alteration took place. The choice of suitable operating parameters will keep the increase in noise and distortion to a practicable minimum. Generally speaking, electrical transfer methods are in a higher state of development than are photographic methods. The increase in distortion and noise to be expected in good re-recording should be considerably smaller than the comparable increase resulting from photographic transfer methods such as good printing. A 16-mm negative produced by re-recording from an optimal fine-grain print of an original sound negative should have appreciably better quality than one obtained from a 16-mm sound negative that has been photographically printed from the optimal fine-grain print of the same original sound negative.

The number of transfer steps as well as the loss characteristics of each step in a production process must be known if the quality of the release prints is to be predetermined. It is the lack of such knowledge that accounts for most of the unsatisfactory 16-mm sound that appears today. The number of transfer steps in a process should be kept to an irreducible minimum; if additional steps must be introduced, electrical re-recording will undoubtedly be necessary to provide optimal equalization of the additional process losses introduced with the minimum possible increase of distortion and noise. Photographic copying will usually result not only in an increase of distortion and noise, but also in an excessive loss of high frequencies. As a practical matter, well-designed and well-maintained re-recording equipment, competently operated, is capable of making a re-recorded copy that has no greater noise than a photographic copy, and yet equalizes the transfer losses without a serious increase in distortion. Such process advantages can hardly be overemphasized.

Most recording systems are arranged to anticipate the losses of but a single transfer step beyond the original sound record; this is usually the making of a photographic print directly from the original sound track negative. If all films were actually manufactured in accordance with this more or less customarily assumed idea, there would be little cause for dissatisfaction with the sound quality of 16-mm films. One of the most serious sources of loss of sound quality is the arrangement of the recording equipment for the making of what has been aptly termed "second generation prints" (such as release black-and-white prints directly from

the sound track negative original) and the actual use of that identical original for photographic copying of an unknown number of "print generations," in which the loss characteristics beyond the second generation are neither known nor taken into account. It is the loss in the aggregate that must be anticipated and corrected for by equalization; accordingly, such "many-generation" prints are definitely bad.

It is more often the rule rather than the exception that correction of such process losses does not occur. Since all stages in the process of making a release print are interdependent, and the losses in each stage are of major magnitude, the importance of knowing the exact number of stages in the process and their characteristics can hardly be overestimated. Without close working arrangements among producers, sound-recording organizations, processing laboratories, and distribution organizations, consistency and satisfaction with the sound quality of the projected picture cannot occur.

Process of Making Release Prints and Effect on Sound

The purpose of an original (sound negative or other) is to provide a method of obtaining release prints by means of a copying process, usually photographic printing. If a small number of copies is required, the simplest and best procedure is to make each release print directly from the original negative. In this process of making copies, the original negative becomes progressively poorer in quality due to wear and tear resulting from handling and aging. The quality of each successive print, despite excellent control of the printing process, likewise becomes poorer. Although the differences between two successive prints made at the same time will hardly be observable in a well-controlled process, the difference in quality* due to normal wear and tear on the original and due to the difference in printing and processing conditions—however slight—will usually be distinctly noticeable between two prints made several months apart. In the case of poor laboratory process control (and this is all too common), there may seem to be little relation between two such prints other than their common origin.

When sound film is photographically copied in a film laboratory, a continuous contact printer is customarily used because of its relatively high operating speed and correspondingly low operating cost. The losses

*The difference in quality referred to is that arising from handling, and is due to scratches, abrasions, and dust. The major variation that occurs as a result is noise.

in even a single copying step are very high; it has been stated that the printer loss when measured as a loss of resolving power in a single step is 30% or greater. The loss due to the film is not inconsiderable; even films of the highest resolving power commercially practicable (150 lines/mm) show significant losses; films of low resolving power (55 lines/mm) are relatively so poor that they should never be used.

Assuming that the film loss is negligible, the maximum possible resolving power of a print from a negative, when printed with a continuous contact printer, is only in the order of 70%. For a large number of copies, duplicate sound negatives might be photographically copied from a master sound print that was likewise printed on a continuous contact printer; release prints would be made from the third generation dupe negatives. Assuming the same printer throughout, the maximum possible resolving powers of fourth and fifth generation prints must be of low order.

Case 1: If the original is a sound negative and a positive release print is desired, the process involves copying at three successive steps.

	100%	×	0.7	×	0.7	×	0.7	= 34%
	original sound negative		sound master positive		sound dupe negative		release print positive	
Generations:	*1st*		*2nd*		*3rd*		*4th*	

The prospect of good sound from such a procedure is slim.

Case 2: If this procedure is carried to a fifth generation, with the original, a sound positive, and a release print desired, the maximum possible resolving power drops further.

	100%	×	0.7	×	0.7	×	0.7	×	0.7	= 24%
	original sound positive		sound dupe negative		sound master positive		sound dupe negative		release print positive	
Generations:	*1st*		*2nd*		*3rd*		*4th*		*5th*	

Each time the film goes through the printer, only some 70% of the resolving power remains; it is certainly reasonable to believe that fifth generation 16-mm photographic prints made on a continuous contact printer are of little commercial value. In practice, even fourth generation photographic 16-mm sound prints are usually of doubtful quality.

Although the foregoing is not rigidly exact because resolving power is used as the sole index of the quality of a print and for numerous other reasons, it is convenient for quickly estimating roughly the possibilities

of a particular procedure. Actually, degradation of sound quality, as mentioned before, appears as:

(*1*) A loss of high frequencies;
(*2*) An increase in noise;
(*3*) An increase in distortion.

As the relationship of the subjective effect of degradation has not been statistically determined with respect to objective effects, it is impossible to establish at this time a quantitative factor of merit that could be accepted generally without major qualifications. Since resolving power is a single objective measure that in some degree encompasses all three specified effects, its use as a qualitative measure for comparison seems reasonable.

Loss of High Frequencies

When a release print is photographically copied directly from a sound negative, the loss of high frequencies resulting from the transfer step is usually equalized in the recording of the negative. Actually, however, there is an upper limit to the amount of electrical equalizing for transfer losses that can be tolerated, since every increase in high-frequency response effected by equalizing produces a noticeable increase in distortion and in noise. Since the original signal being recorded has the least amount of distortion and noise, and has the best signal-to-noise ratio of any stage in the process, it is this point that will ''stand'' most equalizing —minimum distortion and noise will be added for a specified amount of equalizing.

As has been previously described, a direct positive on EK 5372 that has been optimally processed in an enriched D-16 developer bath has an optimal density of approximately 1.5, representing the best compromise between distortion and noise for the purpose. As the density is increased or decreased from this value by changing the exposure, there is an increase in distortion that changes more rapidly as the density deviates from the specified value. If the density is increased, the noise decreases somewhat, but both the distortion and the loss of high frequencies increase; this is caused to some degree by a filling-in of the valleys of the wave pattern recorded upon the film. (Beyond a certain value, the filling-in of the valleys becomes so serious that the output of the film drops due to fog.)

In making a sound print from a sound negative, the optimal density of the negative is approximately 2.00 (emulsion density). This negative,

if closely examined under a microscope, will show a slight filling-in of the valleys of the recorded wave pattern. When such a negative is printed on DuPont 605A or Eastman 5302 under best conditions, and a print is developed in a good developer (such as an enriched D-16), there is a complementary filling-in of the valleys of the wave pattern on the print that introduces an essentially equal and opposite distortion to that found in the negative. Optimal print density for a negative of density 2.00 will be approximately 1.5. Optimal print density depends upon the film, the printing machine, the exposure, and upon the developer and the developing method used. It may be determined by empirical tests (by making a series of test prints from the identical negative over a range of print densities and selecting the test that sounds best) or by means of the cross-modulation test.* Because of the lack of standardization of procedures and of losses in transfer steps, the empirical test will be found more reliable as a production control method. Should a large number of films be handled by substantially the same procedure with the same apparatus, statistical correlation between the empirical and the cross-modulation tests is recommended so that the cross-modulation test may be used routinely because measurement with instruments requires less production time.

Because of the complex nature of emulsion behavior, the density for minimum distortion of a single frequency as recorded by the variable-area method depends upon the harmonic order for which minimum distortion is desired as well as upon the frequency. For complex waves, such as speech, music, etc., the density for minimum distortion depends not only upon the sensitometric characteristics of the materials used and their processing (including printing) but also upon the nature of the sounds recorded. For this reason it would seem that any conventional form of cross-modulation test such as ASA Z22.52 can not hope to be better than a good approximation; the accuracy and the reliability of the approximation can, in a sense, be considered a measure of the reliability of the statistical sampling of the recorded sound.

Generally speaking, if the photographic speed of a film is within the exposure range of the machinery used, highest resolving power and lowest image spread are the characteristics most desired for raw film for variable-area sound uses. By these criteria EK 5372 is the best material available for any variable-area sound purposes but it is not suited for release printing of pictures because it has a blue-dyed antihalation base. At the present time, the widespread use of the readily available present-day good materials under optimal conditions is capable of producing a major im-

* "Cross-Modulation Tests on Variable-Area 16-Mm Sound Motion Picture Prints," American Standard Z22.52–1946.

provement in the over-all performance of present-day 16-mm sound films. The quality potential of today's materials and processes is not being realized and considerable room for improvement still remains.

Increase of Noise

If a negative of density 1.5 is used to make optimal print on release print film such as DuPont 605A or Eastman 5302, it will be found that a print so made will be lower in density and have a measurably higher noise level than an optimal print made from a negative of density of approximately 2.00. When the two prints are compared, the print from the less dense negative will show somewhat better high-frequency response; despite this, the print from the denser negative is preferred because of its appreciably lower noise level.

As the density of the negative is increased beyond 2.00 (emulsion density) the exposure latitude becomes progressively smaller and the high-frequency losses and the distortion become greater. A practicable operating range for negative densities (with good control) is plus or minus 0.1, and a good print can usually be made consistently if the negative density is in this range. Similar tolerances apply to the optimal direct positive density of 1.5. The changes in distortion and noise are relatively small within a density variation of plus or minus 0.1 if all other factors remain the same.

The American War Standard: "Method of Measuring Signal-to-Noise Ratio of Sound Motion Picture Prints," ASA Z52.38-1944,* is considered the most acceptable numerical method available despite the fact that the amount of experience accumulated with it is limited.

Increase of Distortion

Every transfer step introduces distortion in some form or other. Generally, the distortion introduced by an optimal electrical re-recording step is lower than that of an optimal photographic step. Therefore, electrical re-recording should be used in as many transfer steps as practicable when third or later generation prints are to be made.

An optimal print from a sound negative causes an increase in distortion and in noise in addition to a loss of high frequencies. Equalizing during electrical re-recording can offset to some degree the excessive high-frequency losses; the cost is an increase in noise and in distortion in the equalized film. Since the quality degradation per step is quite large in

* Under revision.

photographic transfer steps, the total number of steps permitted between the 16-mm sound original and the release print must be held to the irreducible minimum. With good processing control, intelligible sound can survive on a release print after even three transfer steps; with poor processing control, even a single step is hazardous.

Since it is difficult to specify distortion limits in numerical terms, the primary test should continue to be the empirical test; the routine test may be the ASA cross-modulation test specified. In view of the fact that the relationship between the subjective distortion and the distortion measured objectively by this method has not been definitely established, a combination of listening tests and cross-modulation tests made under identical exposure and processing conditions will probably indicate desirable control limits as measured by the values determined from cross-modulation tests.

General Recording Procedures

With present-day methods and equipment it is difficult to specify rule-of-thumb procedures that do not seem to have many exceptions. This arises from the lack of standardization of the over-all performance of a sound film, components, methods, and of the materials used. At the present time the only over-all requirement that can be stated explicitly is that regardless of how produced, a release print shall be clear, intelligible, and pleasing when projected on an average projector made in accordance with American War Standard Specification JAN-P-49 for a Military Model Projector. The Bell and Howell sound projector currently manufactured is a widely available commercial equivalent performance approximation.

If a small number of black-and-white release prints (less than 50) is to be made at one time, and if there is no need to preserve the original, the best procedure is to record the sound track original as a negative and to make the release prints by photographically copying from the original. Most commercial sound recording equipment is designed to accomplish this kind of recording satisfactorily.

There would seem to be little to choose from among 16-mm negatives recorded upon different makes of good, up-to-date equipment (*e.g.*, RCA, Western Electric, and Maurer). When side-by-side test recordings are made in connection with standardization efforts, the optimal density of a print made on DuPont 605A from similar negatives recorded upon

Eastman 5372 proves to be quite similar under identical processing conditions; prints are excellent in quality and low in noise. Slight differences are observable when the two prints are played back on a 16-mm reproducer system consisting of a film phonograph, a low-noise and low-distortion amplifier, and a two-way theatrical-type loudspeaker system; no difference is observable when the prints are reproduced on a run-of-the-mill commercial projector.

Unfortunately, such high quality is extremely rare in commercially produced release prints. Not only do such tests represent better recording technique, together with better exposure control and better processing control resulting from extra care at each stage, but also the number of transfer steps anticipated and their characteristics in the aggregate are in close accordance with the conventional design objective of the recording equipment. Even with a median level of control, results of such operation would still be of a superior order compared with conventional commercial films because of the use of but one transfer step between the original sound record and the release print.

Unfortunately, most release prints are not made in that simple and straightforward manner. The number of prints required is often far in excess of the maximum number that can be copied from a single piece of film; the physical wear-and-tear on the original accumulated in printing will result in damage and ultimately in mechanical breakdown of the original. What happens in an unplanned procedure is that at some indeterminate time prior to complete breakdown, when the evidences of breakdown are already all too apparent, a duplicate negative is photographically copied from one of the last release prints made from the original negative; then fourth generation prints are made from the duplicate negative. The result is usually poor; in most cases it can hardly be called even marginal.

Practical Method Suggestions

Even with the very best 16-mm machinery, materials, and methods not even third generation prints can be called wide range or high fidelity—the transfer losses are too great. With very good process control, a third generation print made from a re-recorded negative can be made quite satisfactory for conventional projection. To do this successfully demands that every portion of the process be supervised carefully and the losses in each stage must be kept to an absolute minimum. To limit the

distortion added by the extra transfer steps the following procedures will be necessary.

(*1*) Equalize only partially for the high-frequency losses introduced by re-recording with response-frequency characteristics that are "boosted" at the high-frequency end of the spectrum. The frequency of maximum amplification will customarily be located somewhat lower than the upper frequency cutoff; the practicable amount is limited to some 12 db. It is not practicable ordinarily to equalize more than this amount because of the excessive noise and excessive distortion that would occur as a result.

(*2*) When re-recording, reduce the frequency range by the use of appropriate band-pass filters. The range should be reduced in *full steps* in accordance with Table XIV. If excellent control of processing is present, a reduction of one full step may be sufficient; for more conventional control, a reduction of two or three steps will be needed. (For example, if the original was recorded with range *F*—110–5300 cps—the range would be limited to range *G*—130–4400 cps—for excellent control, to range *H*—160–3600 cps—or ranges *I* or *J* for more conventional control.) Much depends upon the intermodulation distortion present.

(*3*) Limit the working signal-to-noise ratio by introducing compression of the volume range. Assuming a 25-db signal-to-noise ratio for an original 16-mm speech sound record, a compression of some 5 db will usually be sufficient for excellent process control with projection of the print under excellent acoustical conditions, with an excellent sound projector; and some 10 db for more conventional control with projection of the print under more conventional acoustical conditions with more conventional sound projectors.

In considering the corrections to be applied, it is reasonable to ask how the optimal amounts of each of the above corrections may be determined. Unfortunately, no simple rule-of-thumb is available, since the relationships between the objective factors and the subjective factors have not been determined statistically. For this reason the criterion must be subjective; it is merely "the method that produces the most pleasing print for the reference projector used under the reference projection conditions." Even if this criterion were satisfied accurately, the variation in performance of commercial projectors and the variations in auditorium characteristics (such as size, noise, reverberation, etc.) are often large enough to preclude satisfactory operation over such wide ranges.* Satisfactory operation presumes modern, well-maintained projectors together with an auditorium where ordinary conversation can be maintained at typical loudspeaker-to-listener distances.

Selected Bibliography

Fletcher, H., *Speech and Hearing*. Van Nostrand, New York, 1929.

Pender-McIlwain, *Electrical Engineers' Handbook—V, Electrical Communication and Electronics*. Wiley, New York, 1936.

*The acoustic performance characteristics of 6 commercial projectors are shown at the end of Chapter XIII.

Society of Motion Picture Engineers, *The Technique of Motion Picture Production.* Interscience, New York, 1943.

Academy of Motion Picture Arts and Sciences, *Recording Sound for Motion Pictures.* McGraw-Hill, New York, 1931.

Research Council, Academy of Motion Picture Arts and Sciences, *Motion Picture Sound Engineering.* Van Nostrand, New York, 1938.

Wood, A., *Acoustics.* Interscience, New York, 1946.

Beranek, L., *Acoustic Measurements.* Wiley, New York, 1949.

Olson, H., *Elements of Acoustical Engineering.* 2nd ed., Van Nostrand, New York, 1949.

Batcher and Moulic, *Electronic Engineering Handbook.* Electronic Development Associates, New York, 1944.

Henney, K., *Radio Engineering Handbook.* McGraw-Hill, New York, 1935.

Frayne and Wolfe, *Elements of Sound Recording.* Wiley, New York, 1949.

Jensen Radio Manufacturing Company, *Technical Monographs No. 1 to 5.* Chicago, 1945.

Steinberg *et al.*, ''The Stereophonic Sound-Film System,'' *JSMPE, 37,* 366 (Oct. 1941).

Durst and Shortt, ''Characteristics of Film Reproducer Systems (35-mm),'' *JSMPE, 32,* 169 (Feb. 1939).

Loye and Morgan, ''Sound Picture Recording and Reproducing Characteristics (35-mm),'' JSMPE, *32,* 631 (June 1939); *33,* 107 (July 1939).

Scott, H. H., ''Audible Audio Distortion,'' *Proc. Natl. Electronics Conference* (Illinois Institute of Technology), *1,* 138 (Oct. 1944).

Olson, H. F., ''Extending The Range of Acoustic Reproducers,'' *Proc. Radio Club Am.*, *(N. Y.)*, *18,* 1 (Jan. 1941).

Frayne and Scoville, ''Analysis and Measurement of Distortion in Variable Density Recording,'' *JSMPE, 32,* 648 (June 1939).

Hilliard, J., ''Distortion Tests by the Intermodulation Method,'' *Proc. I. R. E., 29,* 614 (Dec. 1941).

Albin, F. G., ''Intermodulation Distortion of Low Frequencies in Sound Film Recording,'' *JSMPE, 46,* 4 (Jan. 1946).

Sandvik and Hall, ''Wave-Form Analysis of Variable-Density Sound Recording,'' *JSMPE, 19,* 346 (Oct. 1932).

Sandvik *et al.*, ''Wave-Form Analysis of Variable-Width Sound Records,'' *JSMPE, 31,* 323 (Oct. 1932).

Evans and Lovick, ''Zero-Shift Test for Determining Optimum Density in Variable-Width Sound Recording,'' *JSMPE, 52,* 522 (May 1949).

SMPE Committee on Sound, ''Proposed Standard Specifications for Flutter or Wow as Related to Sound Records,'' *JSMPE, 49,* 147 (August 1947).

Baker and Robinson, ''Modulated High-Frequency Recording as a Means of Determining Conditions for Optimal Processing,'' *JSMPE, 30,* 3 (Jan. 1938).

Livadary and Twining, ''Variable Area Release from Variable Density Original Sound Tracks,'' *JSMPE, 45,* 383 (Nov. 1945).

Reiches, S. L., ''Volume Distortion,'' *JSMPE, 38,* 457 (May 1942).

Bruno, M., ''Maps on Microfilm,'' *JSMPE, 41,* 421 (Nov. 1943).

National Bureau of Standards, Circular C439, *Acoustic Performance of 16-Mm Sound Motion Picture Projectors.* Supt. of Documents, Washington, D. C., 1942.

Johnson, W., ''Analyzing Sweep Frequency Transcriptions,'' *Audio Eng.* (*N. Y.*), *31,* 18 (Oct. 1947).

Haynes, N. M., ''Factors Influencing Studies of Audio Reproduction Quality,'' *Audio Eng., 31,* 15 (Oct. 1947).

Minter, J., ''Audio Distortion,'' *Radio Club Am.*, Dec. 1944.

Tanner, R., ''Audio Technique in Television Broadcasting,'' *Audio Eng., 33,* 9, (Mar. 1949).

Offenhauser and Israel, ''Some Production Aspects of Binaural Recording for Sound Motion Pictures,'' *JSMPE, 32,* 139 (Feb. 1939).

For further bibliographic material the reader should refer to the following indexes to the *Journal of the Society of Motion Picture Engineers.*

July 1916–June 1930

January 1930–December 1933

1936–1945

CHAPTER IX

Sound-Recording Equipment and Its Arrangement

History

Component Units

When 35-mm sound film-recording equipment for variable area was first introduced commercially in 1928, it was quite simple in arrangement. The original sound record was a negative, and the release print was contact printed directly from the original. The three major components of the equipment were:

(*1*) The microphone—this was a condenser type with an associated amplifier of approximately 40-db gain and filament-type electron tubes energized by batteries. (The double-button carbon microphone had already been superseded because of the excessive noise from its carbon granules.)

(*2*) The amplifier—this was a simple cascade amplifier using filament-type triode electron tubes also energized by batteries. The gain was approximately 60 db, and the output power was from about 200 to 500 milliwatts.

(*3*) The sound-recording machine—this consisted of:

(*a*) A simple film transport system utilizing a film-driven flywheel similar to that used on some current 16-mm sound projectors such as the Ampro.

(*b*) A light modulator that was a simple oil-damped Dudell string-mirror oscillograph—as commonly found in electrical laboratories.

(*c*) An optical system to transfer the motion of the oscillograph mirror into a dimensional form suitable for recording a sound negative.

Figure 31 is an illustration of the unbiased unilateral negative sound track that was produced. A positive print from that negative is also shown.

When compared with present-day practices, the film—which was ordinary printing positive—was poor; its resolving power was 50 lines per mm or less as compared with 150 lines per mm for modern films (such as Eastman #5372). But in 1928, the same film stock that was used for the variable-area sound negative was also used for the release print.

The transfer losses were high and were not consistent from subject to subject or from print to print. Despite the magnitude of the losses, the over-all result was not as bad as might be expected, because only one transfer step was encountered from negative original to the release print.

The over-all response-frequency characteristic of this early equipment did anticipate to a degree the transfer losses encountered; the intent was correction to the release print. The low-frequency response of the amplifier was reduced by the simple expedient of reducing the capacitance of the interstage coupling capacitors; this corrected to some degree for such factors as the difference between the recording level and the reproducing level, for voice effort, for voice quality, and the like. High-frequency losses were somewhat compensated by the resonance peak of the oil-damped galvanometer which was some 6 or 8 db between the frequencies of 5000 and 6000 cps. A certain amount of "presence" was added quite unavoidably by the pressure-doubling peak of the condenser microphone cavity which produced a sharp rise in response at about 3000 cps.

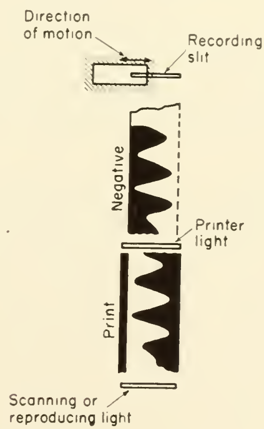


Fig. 31. Unilateral variable-area sound track, unbiased—negative and print. Horizontal motion of the rectangular recording light beam across the slit provides modulation of the track.

There were no equalizers or filters to correct for nonlinearities of microphone, amplifier, or galvanometer; no means was generally available for altering the frequency range or the dynamic range as desired. In some respects, there was little need for such versatility.

There was little 16-mm sound-recording equipment in existence in this period before 1931; most of it was scaled-down 35-mm equipment in which the major modification was merely the substitution of 36 for 90 feet-per-minute speed for the 16-mm film.

As a practical matter, the amplifiers of this early sound-recording equipment were quite microphonic; it was a few years before nonmicrophonic electron tubes first made their appearance on the market. The filament-type tubes so familiar at that time (240, 201A, 112A, and 171A) are now obsolete; even the 864, the first nonmicrophonic tube that ap-

peared in 1928 is now no longer used in commercial sound film recording equipment. The preamplifiers associated with condenser microphones were shock mounted and acoustically insulated; on the whole, the designs were effective in materially overcoming the very serious handicaps of the microphonic tubes.

General Requirements for Modern 16-Mm Sound-Recording Equipment

Modern 16-mm sound-recording equipment should be capable of recording sound in whatever manner is required to accomplish the specific objective of the particular film being produced. As far as sound recording is concerned, desired objectives range over very wide limits. One limit may be the recording of a direct positive of highest fidelity and widest dynamic volume range practicable on 16-mm film for direct playback in a very quiet and acoustically well-treated review room with the film run on a high-quality film phonograph and reproduced through a wide-range amplifier and speaker system. The other limit may be the recording of a sound negative from which release prints will be derived by means of, say, four transfer steps, and the release print projected in an ordinary untreated schoolroom with a run-of-the-mill sound projector. To accomplish the former satisfactorily requires equipment of the highest fidelity and of the widest practicable dynamic volume range; the latter requires the same basic equipment with the frequency range altered by suitable corrective networks and the dynamic volume range limited by suitable volume compressors or limiters. The reverse situation will not work; it is impossible to take basic equipment of limited frequency range and of limited dynamic volume range and record high quality sound film with it.

Equipment that is wide in range has the great advantage that any ordinary change of frequency range, volume range, or both requires little more than the change of a corrective network and an adjustment for the dynamic range. This is simpler than the purchase of a completely new recording equipment for each new range or condition. Wide-range equipment is not cheap; its cost is measured in thousands of dollars rather than in hundreds. Such equipment must have day-to-day reliability without drift or sensible change in its wide frequency range, in its low noise content, and in its low distortion; its performance must be as consistent as the best high-fidelity broadcast station for frequency modulation sound transmission.

When corrective networks, equalizers, compressors, limiters, or any other arrangements are used to modify the frequency range or the dynamic volume range, it must be ascertained that each such arrangement does not of itself introduce appreciable noise or distortion—at least not more than actually expected. In practice, serious noise and distortion can creep in almost unnoticed because of the hum and other noise induced in poorly shielded coils of the inductors used in filters and equalizers. Such coils should never be placed in the strong stray magnetic fields of power transformers and power reactors; the influence of such fields may often be minimized by orienting the coil or transformer with respect to the disturbing field. Manufacturers of commercial filters and equalizers customarily shield them magnetically against hum pickup and likewise make the inductors as small as physically possible to limit the noise voltages induced. Unfortunately there is no standard method of rating the effectiveness of such shielding; as a result it is nearly impossible to distinguish between the presumably equivalent products of different manufacturers, or, in fact, to distinguish between good and bad on the basis of published data.

It is always good practice to check the increase in noise and distortion in a sound circuit when a corrective network is introduced. Every precaution possible should be exercised to avoid the introduction of noise, since it is not uncommon for an otherwise excellent network to introduce sufficient hum to make it worthless as a practical device.

Corrective networks are introduced to provide "the most pleasing release print for the reference projector used under the reference projection conditions." Since it is impossible to divorce the over-all characteristics of the system from the component characteristics of any and all links in the process chain, some of the important factors in the chain should be listed for reference. These are:

(*1*) The character of the original sound to be recorded.

(*2*) The dramatic and other effects to be introduced.

(*3*) The noise, the reverberation, and the other acoustic characteristics of the space surrounding the pickup microphone.

(*4*) The response characteristics of the microphone—frequency and directional response.

(*5*) The performance of all amplifiers and other equipment located between the microphone and the light modulator or galvanometer.

(*6*) The properties of the light modulator, the noise reduction system, the compressor or limiter, and all related equipment.

(*7*) The performance of the film upon which the original sound track is recorded. (Performance variations may be very large due to variations in exposure and processing as well as to the film.)

(*8*) The number and variety of transfer steps actually used between the original sound record and the release print, and the over-all characteristic of the steps used. (Performance variations are particularly large at this point because of (*a*) differences in the number of transfer steps used, (*b*) variations of a particular step from time to time, as well as (*c*) variations due to different printing machines and different processing baths, and variations in performance of such printing machines and baths from time to time.)

(*9*) The performance of the projector upon which the release print is run. (The same print will sound very different when run on projectors of different makes and models. A Kodachrome or other color reversal duplicate with the nonstandard emulsion position will sound very different when projected upon a projector that has sound optics focused on the correct side of the film as compared with the same optics focused on the opposite side.) The performance of the loudspeaker used is very important.

(*10*) The noise and reverberation characteristics of the auditorium or other listening space within which the audience listens to the film.

(*11*) The difference in volume level between the original sound and the reproduced sound.

(*12*) The mechanical noise made by the projector—where the projector is located with respect to the audience (preferably, it should be located in a booth outside of the projection auditorium where it cannot be heard).

(*13*) The noise emitted by the projector loudspeaker resulting from the hum, hiss, microphonic jangle of the electron tubes and of the exciter lamp (the light source of the scanning beam), and similar noises. In a sound projector, all sound issuing from the loudspeaker should theoretically result from the light variation caused solely by the passage of the intended record on the film past the sound-scanning beam. Practically, however, the noise level of disturbances produced within commercial optical and amplifier systems is usually of significant order compared with the noise found in the film itself. One common source of noise that is overlooked or seriously underestimated is that produced by the exciter lamp. Hum often occurs due to incomplete filtering of the current supply; the thermal lag of the average lamp is small because its filament is small in cross section. Although the lamp filament is under tension, the natural vibratory period of the lamp drops considerably when the lamp is heated. Microphonic noise is caused by a ''wriggling'' of the lamp filament with respect to the optical axis and is caused by mechanical vibration. In many cases the disturbance frequencies are in substantially the same frequency range as the disturbance frequencies produced by flutter and other speed irregularities. (A microphonic exciter lamp thus seriously aggravates the disagreeable audible effects of speed irregularities.) A quick qualitative evaluation of the amount of noise contributed by the exciter lamp can be made by listening to the noise from the loudspeaker with the motor turned off, and with a card temporarily blocking the light beam—preventing it from entering the photocell. The noise heard is compared with the noise produced when the motor is running and the light beam entering the photocell without any object in its path. (It is customary for measurement puposes to use a neutral density filter of density 0.3 in the light beam; for qualitative purposes this refinement is not necessary.) In both cases the gain setting of the amplifier and its tone control setting and other adjustments should be the same; these should preferably be the settings used when the projector is running films in a large auditorium. The difference between the two conditions will be noticeable in all commercial projectors, and quite marked in some.

In general, commercial projectors made in the largest quantities are designed so that the performance of one part of the sound system, *e.g.*, the sound-scanning system, is just about "matched" economically to the other parts, such as the amplifier and the loudspeaker. To obtain significant improvement in performance in such "economically matched" designs would require an improvement in all portions of the sound-reproducing system from the scanning system to the loudspeaker. In certain of the higher grade sound projectors such as the Bell and Howell, the loudspeaker represents the "quality bottleneck," and significant improvement can be obtained by merely replacing it with one of better grade, such as the W.E. Co. 755A, in an appropriate baffle.

(*14*) The fidelity of the sound projector—its frequency response and its dynamic range.

Unfortunately there has been no standardization of the performance of even one of the foregoing factors. A direct result of the absence of such standardization is the relatively high cost of sound recording and its poor uniformity and quality in performance. Strenuous efforts should be made by organizations concerned to "tie down" the performance of release prints and of projectors; from this performance, the required standardization of recording equipment and its components can be evolved.

Transfer Losses and Their Correction

It may well be asked: "Why is there so much emphasis on the subject of electrical response-frequency equalizers, and why are such equalizers suggested when shortcomings are found in *other* portions of the recording, processing, and reproducing processes?"

In general, in any transmission system, the mid-range system losses (such as those that occur at approximately 800 cps) are lower than those occurring at either of the range extremities. It is difficult and often impossible to design components of the system with a theoretical zero-loss characteristic; this is especially true of transducers, such as microphones, light modulators, and loudspeakers. As has already been pointed out, loudspeakers and amplifiers become larger and more costly when the frequency range is extended downward; the high-frequency losses become greater and the noise factor becomes more serious as the frequency range is extended upward.

Amplifiers are far easier to control in response-frequency characteristics than are other components. Equalizers that are relatively inexpensive and easy to design and build are capable of readily altering the response-frequency characteristic of an amplifier with which they are associated. On the other hand, if the response-frequency characteristic

of a recording galvanometer is different from that desired, there is nothing a user can do to alter its characteristics to the need of the moment. Generally speaking, it is recording practice to use equalizers that more or less exaggerate, at the time of recording, the amplitudes of the high-frequency components of the sound to be recorded. The purpose is to compensate for the high-frequency losses anticipated in the remainder of the developing, copying, and reproducing process. Unfortunately the greater the losses encountered, the more variable they usually are, and the more difficult it is to compensate satisfactorily for them. The introduction of equalizers for the correction of transfer losses is in reality an expedient adopted for the sake of obtaining a commercially acceptable over-all result at low cost rather than a fundamental solution for eliminating or reducing transfer losses. Such equalizing is accomplished only at the cost of an increase in distortion and in noise; one should ascertain that the best compromise among the three factors has been obtained for the particular conditions to be met. The only fundamental corrections for a transfer loss are improved equipment, improved material, and improved operating techniques.

Recommended Ranges of Response-Frequency Over-all Characteristic

The quality of the best commercial 16-mm recording has improved markedly since 1930. This improvement has been the result not only of modifications and improvements of the elements present in the early equipment of more than a decade ago, but also of the introduction of entirely new elements. Most of the additional complexity has been electronic; it has had as its purpose the extension of the frequency range and the reduction of noise and distortion. More electron tubes have been added together with more controls; because of the limitations of manual control, the added controls have had pre-set adjustments and are to a great extent automatic.

Now that recording equipment and film have been improved to the point where desired performance can be obtained within the limitations of the best available sound projectors, it would seem practicable to specify the frequency ranges within which the recording equipment should operate; these are selected from the table of preferred frequency ranges listed in an earlier chapter. These recommendations presume single-channel transmission.

Ranges *F*, *G*, and *H* will probably be used most frequently. Ranges *D* and *E* in the better fidelity region and range *I* in the poorer fidelity

region will probably be used infrequently. Range *C* in the high fidelity region and range *J* in the low fidelity region will probably be used but rarely. When release prints are to be projected under varying conditions that are not known precisely, or where processing is not under very close supervision and control, it will probably be preferable to use filters for the narrower range rather than for the wider if there is a choice between two adjacent ranges. The figures in the table may be used as the basis of the design for the band-pass or equivalent filters in limiting the frequency range of the recording equipment. In addition to the range-limiting filters, equalizers will be needed to correct for the transfer losses and other transmission defects.

TABLE XV

Range	Frequency, cps	Range	Frequency, cps
C	75–8000	*G*	130–4400
D	80–7600	*H*	160–3600
E	90–6400	*I*	200–3000
F	110–5300	*J*	220–2700

Figure 32 shows some typical equalizer and correction characteristics together with their functions. The band-pass filter (which may also be called a range-limiting filter) merely consists of two filters connected in tandem; a low-pass filter that limits high-frequency response, and a high-pass filter that limits low-frequency response.

Pre- and Post-Equalizing

Pre- and post-equalizing deserves special mention because it is capable of extending the useful signal-to-noise ratio by about 5 db beyond that usually possible. Essentially, this involves recording with the higher frequencies accentuated further, and, correspondingly, intentionally attenuating the higher frequencies in reproduction. This recording technique, which was first used commercially by Electrical Research Products Division of Western Electric in their equipment for hill-and-dale (vertical) cut transcription records for broadcasting and for wired music service, has since been universally adopted for broadcast transcription use on all the 33 1/3-rpm lateral cut records. Figure 33 shows the characteristics and constants of the NAB-RMA pre- and post-equalizers.

Pre- and post-equalizing has since been adopted for original 35-mm sound track for Hollywood-produced films. Figure 34 shows the constants

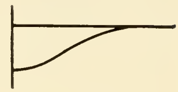
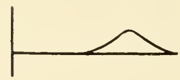
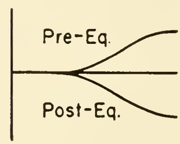
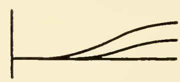
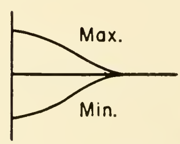
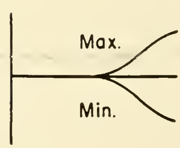
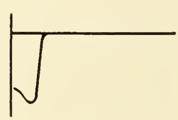
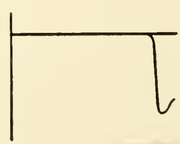
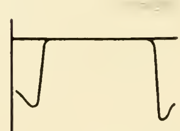
Network	*Function*	*Service*	*Response*
Dialog Equalizer	Compensates for voice effort and quality	Recording	
Microphone Equalizer	Compensates for microphone irregularities or certain acoustical response effects.	Recording	Depends upon microphones used
Presence Equalizer	Corrects for certain acoustic pick-up effects.	Recording	
Pre-Equalizer Post-Equalizer	Increases highs subsequently attenuated in reproducing. Used to reduce noise.	Recording and Reproducing	
Film Equalizer	Compensates for film losses.	Re-recording	
Low-Frequency Corrective	Permits adjustment of response for corrective or dramatic effects.	Re-recording	
High-Frequency Corrective	Permits adjustment of response for corrective or dramatic effects.	Re-recording	
High-Pass Filter	Limits low-frequency response.	Recording and Re-recording	
Low-Pass Filter	Limits high-frequency response, depending partially upon modulating device characteristic.	Recording and Re-recording	
Band-Pass Filter	Limits low- and high-frequency response, depending partially upon modulating device characteristic.	Recording and Re-recording	

Fig. 32. Equalizer and correction filters and their functions.

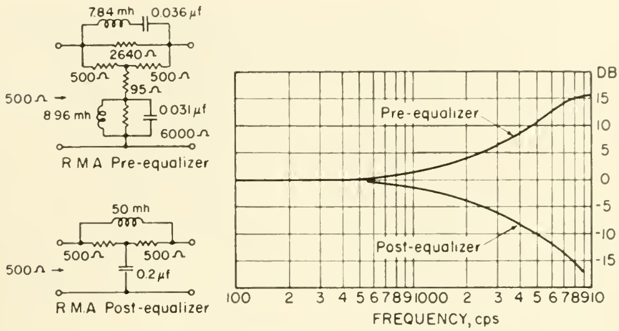


Fig. 33. NAB-RMA standard pre- and post-equalizers. A new standard will probably be prepared, since this standard calls for considerable high-frequency equalizing which results in excessive distortion in wide-range high-fidelity systems.

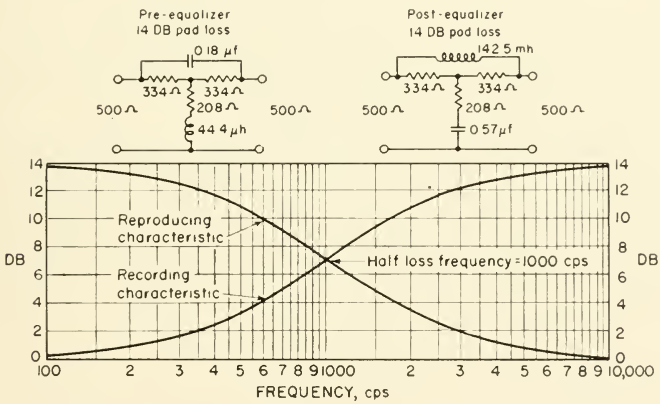


Fig. 34. Academy of Motion Picture Arts and Sciences (Hollywood studios) pre- and post-equalizers. This standard is several years old and will probably be revised for the same reason as the equalizer of Figure 33.

and characteristics of the equalizer recommended by the former Research Council of the Academy of Motion Picture Arts and Sciences. Since negatives from which release prints are made are re-recorded from the original sound track or from a print from the original sound track, pre- and post-equalizing proves a most desirable means materially offsetting the transfer losses and the increase in noise between the original sound record and the re-recorded release negative.

Pre- and post-equalizing played a very important part in the excellence of performance of the stereophonic sound demonstration of the Bell Telephone Laboratories such as the demonstration at the Eastman Theater

in Rochester, New York, on May 7, 1941. Although the complexity and high cost of the equipment used puts it far out of reach for day-to-day commercial use, the performance was of such high caliber that the considerations prompting the system and equalizer designs are worthy of very careful study by those who wish to make the best use of available facilities.

As yet, little serious thought has been given to pre- and post-equalizers for 16-mm recording. The recent improvements in competitive methods of sound recording, such as magnetic recording and recording on disk, and the recent improvements in available films, will no doubt bring this and any other means of improving sound quality quickly to the attention of manufacturers' designers.

Much has been written on the subject of equalizer design and theory. The Bell System and its affiliates have made notable contributions to the theoretical background as well as to practical structures; it has been said that the transmission of a telephone conversation for more than 100 miles would be impossible without equalizers. At the end of this chapter are a number of references on the subject.

Because of the somewhat involved nature of equalizers, the most practicable procedure for an owner of recording equipment who needs equalizers is to consult the manufacturer of the recording equipment that he uses. A number of manufacturers supply equalizers of more or less standardized designs; other equalizers are made to specifications. Some of the manufacturers are:

Cinema Engineering Company, Burbank, Calif.
United Transformer Corp., New York, N. Y.
Audio Development Corp., Minneapolis, Minn.
The Langevin Company, New York, N. Y.
Altec-Lansing, New York, N. Y.
General Radio Company, Cambridge, Mass.

The mailing addresses of the above companies may be obtained from any one of a number of yearly electronics directories such as *Electronics*, McGraw-Hill Publishing Company, or *Electronic Industries*, Caldwell-Clements Publishing Company, or from any commercial directory. Ordinarily, RCA and Western Electric will supply equalizers only to their licensees; their equalizers are usually not for sale in the open market.

Characteristic Impedance

The impedance for which a device or circuit is designed is one that will provide the transmission characteristics for which the device or

circuit is designed. Ordinarily, the use of a device or circuit at an impedance different from its characteristic impedance will be unsatisfactory. As a general rule the circuit impedance in which a device is used is satisfactory if it is within 5 to 10% of the rated impedance.

A variety of designs is available for connection in lines of 600 ohms characteristic impedance (600 ohms input impedance, 600 ohms output impedance). The number of types stocked by manufacturers for other characteristic impedances is smaller than those stocked for 600 ohms; most manufacturers can supply filters designed for other impedances at higher cost or as made-to-order items. So far the trend has been in the direction of 600 ohms as the preferred impedance; it is expected, however, that a connection impedance of 150 ohms may be nationally standardized for broadcasting and similar purposes as the suitable impedance for audio circuits of higher fidelity. At present many manufacturers design amplifiers for a circuit impedance of 550 ohms; ordinarily such amplifiers will function satisfactorily with equalizers and attenuation pads of either 500- or 600-ohms rating.

A variety of connection impedances has been used by manufacturers, and despite the urgent need, there has been no national standardization. Western Electric uses 30 ohms as the common connection impedance for microphones, and 600 ohms for other circuits. RCA, on the other hand, uses 250 ohms as the common connection impedance for microphones and 250 and 500 ohms for other circuits. When purchasing audio equipment of any kind, it is important to pay special attention to the impedances for which it is designed to make certain that it may be connected directly to equipment in service.

Recording Equipment Details

The Microphone

A microphone has been defined as a device that transfers power from an acoustic system to an electrical system. Since sound is a series of alternating compression and rarefaction waves that occur in the air, a microphone is a device that is placed in a sound field to produce an electrical wave that closely resembles the sound wave in form. When a microphone is placed in a sound field, a small portion of the energy of the sound wave actuates the microphone.

Any convenient form of voltage generating electrical arrangement can be used for a microphone. Among the more common are:

(*1*) The movement of an electrical conductor in a magnetic field. The magnetic field in modern microphones is provided by a permanent magnet, while some early microphones used an electromagnet to provide the necessary field flux. The conductor of the microphone and the sound responsive part may be one and the same: a velocity microphone, as shown in Figure 35, is one example of such an arrangement. The conductor and the sound responsive part of the microphone may be different, or they may be mechanically coupled. A diaphragm may be used to intercept more sound energy; the conductor may be wound as a coil to increase its length and to increase output level; the increase in length of the conductor is made as large as the increase in sound energy intercepted allows. A moving-coil dynamic microphone is an example of such an arrangement; one is shown in Figure 36.

(*2*) The movement of a diaphragm that forms a movable plate of a capacitor. If a polarizing potential is applied to a capacitor, variation of its capacitance by a sound wave will cause a change in capacitor charging current that can be used to

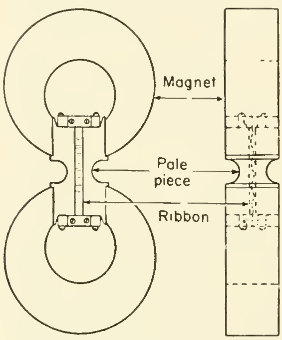


Fig. 35. Essential elements of a velocity microphone (ribbon microphone).

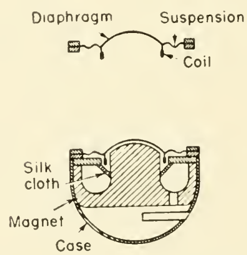


Fig. 36. Cross-sectional view of a moving coil (dynamic) microphone.

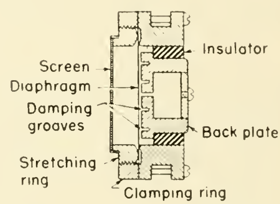


Fig. 37. Cross-sectional view of a condenser microphone.

activate an associated amplifier. A condenser microphone of a type formerly in wide use is an example of such an arrangement; one is shown in Figure 37.

(*3*) The movement of a piezo-electric crystal. The crystal face and the sound responsive part of the microphone may be one and the same; a sound cell microphone, as shown in Figure 38, is one example. As in the case of the moving-coil microphone, the electrical generator and the sound responsive part may be different. A diaphragm may be used to increase the amount of sound energy intercepted, as shown in Figure 39; a larger crystal assembly may be linked to the diaphragm to take advantage of the larger amount of mechanical energy available for driving the crystal.

(*4*) The variation in contact resistance of carbon granules or other pressure-sensitive, resistance-varying arrangement. The most common example of this form of energy converter is the carbon-button microphone, such as shown in Figure 40; the single-button microphone that is very widely used in commercial telephones, and the double-button carbon microphone, such as shown in Figure 41, that was used widely in broadcasting stations before the better forms, such as the magnetic and condenser types, were available. In one usual construction the sound-responsive diaphragm acts

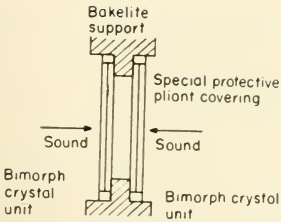


Fig. 38. Cross-sectional view of a crystal microphone—sound cell type.

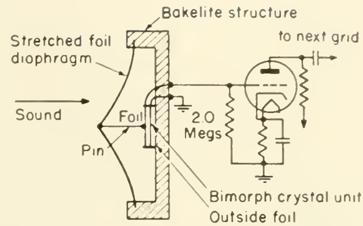


Fig. 39. Cross-sectional view of a crystal microphone — diaphragm-actuated type. Electron tube amplifier input tube is shown.

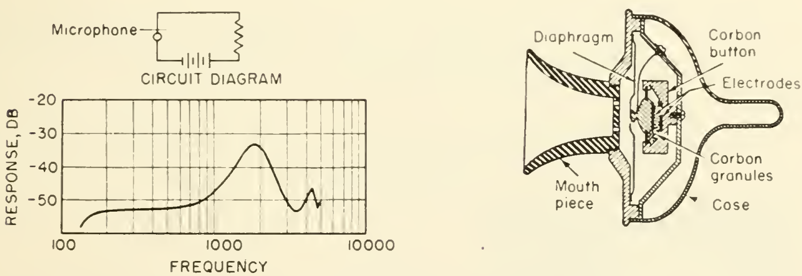


Fig. 40. Cross-sectional view and electrical circuit diagram for single button carbon microphone. The curve shows a typical free-space open-circuit voltage response-frequency characteristic.

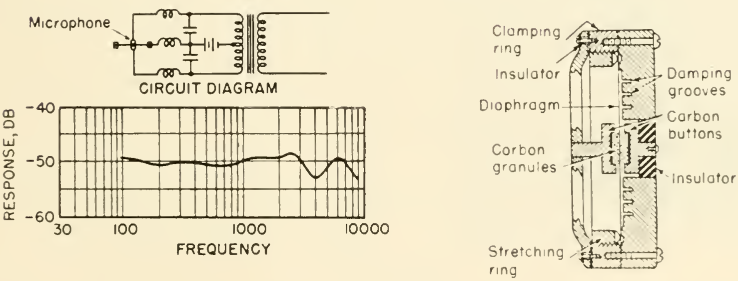


Fig. 41. Cross-sectional view and electrical circuit diagram for double-button stretched diaphragm carbon microphone. The curve shows a typical open circuit voltage response-frequency characteristic for constant sound pressure on the diaphragm. (*Note:* The inductances and capacitors shown are used for current-surge limiting to prevent the carbon granules from sticking together as a result of arcing among granules.)

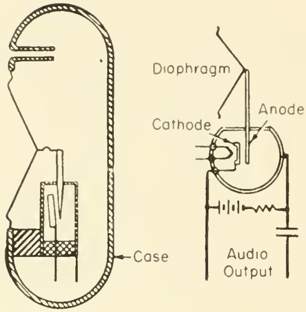


Fig. 42. Cross-sectional view and electrical circuit diagram of an electronic microphone.

also as one contact plate of the carbon button; in another, the sound responsive diaphragm is mechanically linked to the movable plate of the carbon button.

(*5*) The physical movement of an electrode of an electron tube. As in other generator forms, a diaphragm may effect the physical movement of a control electrode. This form of generator is relatively new and is not widely used; it is shown in Figure 42.

The low-impedance, moving-conductor, magnetic-type microphone has displaced almost all others for sound pickup; carbon and crystal micro-

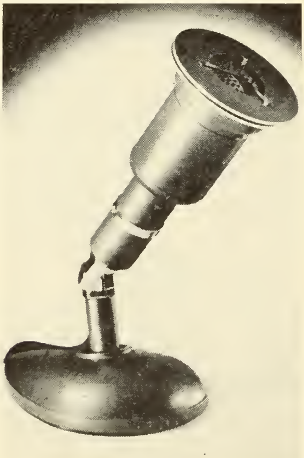


Fig. 43. Western Electric 633A microphone with 8B microphone attachment (baffle)—mounted on 24A stand.

Specifications

Frequency response: See Figures 43A and B. *Power output level:* When terminated by a resistance of 20 ohms the power output level is -59 dbm (0 level calibration 1 milliwatt 10 dynes/cm^2), -79 dbm (1 dyne/cm^2). *Sensitivity:* Open circuit terminal voltage 90 db below 1 volt/dyne/cm^2 which is equivalent to 70 db below 1 volt/10 dynes/cm^2. *Output impedance:* Voice coil 20 ± 2 ohms. *Dimensions:* 3½″ long by 2″ diameter. *Finish:* Dark aluminum gray. *Directional properties:* See Figures 43A and B.

phones are very rarely used. Permanent magnets are now used almost exclusively for providing the magnetic flux in such microphones; electromagnets have been displaced entirely because of the improvements that have been made in permanent magnet materials in the last decade. All modern microphones are characterized by the smoothness of their response; the very jagged variations in the response-frequency characteristic of the microphones of a decade ago are now largely a thing of the past.

Pressure-Operated Microphones

Since commercial recording equipment is "single eared" and cannot provide that most desirable directional discrimination exhibited by

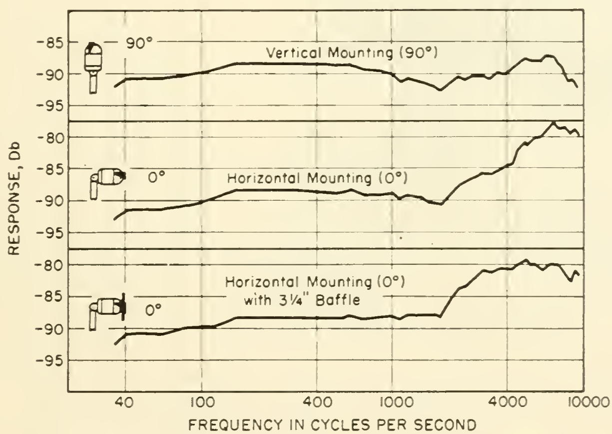


Fig. 43A. Field response of 633A microphone.

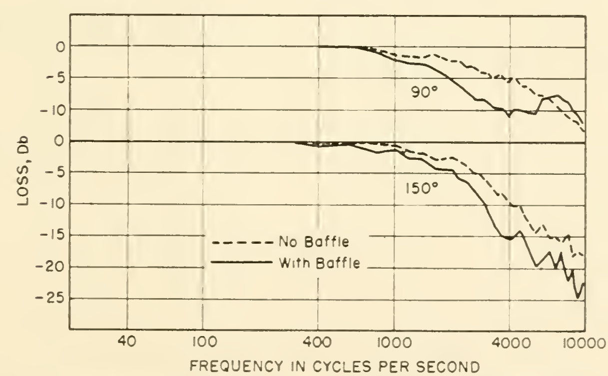


Fig. 43B. Loss in field response of the 633A microphone for sound of angular incidence.

human ears, the directional characteristics of a microphone chosen may be expected to make a very great difference in the final result. Ideally, microphones are either nondirectional and respond equally well to sounds arriving from all angles in the vertical and in the horizontal planes, or they are directional and favor sounds originating from certain directions over sounds originating from other directions. With either a nondirectional or a directional microphone, the ideal requires that the response shall be substantially the same at all frequencies. Practical

Fig. 44. RCA 88A pressure microphone (moving coil) MI-3044.

Specifications—Type KN-2A (for Sound Films)

Directional characteristic: Nondirectional
Output impedances: 25, 50, 250 or 500 ohms
Output level at 1000 cy.*: −55 db (0 db = 0.001 watts); −63 db (0 db = 0.006 watts)
Frequency response (see Fig. 44B): 60 to 10,000 cycles

Finish: black wrinkle
Dimensions (overall)
Height: $3\frac{7}{8}''$
Depth: $4\frac{1}{8}''$
Width: $2\frac{3}{16}''$
Weight (unpacked): 1 lb., 14 oz.
Stock identification: MI-3044D

microphones do not meet the requirements of the theoretical ideal; yet, as each new microphone is developed, it seems to approach more and more closely the theoretical goal.

The need for a good directional microphone is obvious; an ideal microphone should "listen to" the sound that it is intended to hear, and to discriminate against other sounds and noises. A microphone that is uniformly "live" through an angle of 90° in the front and uniformly "dead" through the remaining 270° to the rear would be a great con-

* Input sound pressure of 10 dynes per square centimeter.

tribution toward improved sound recording. Such a directional characteristic would be described by the general term cardioid although its use is incorrect in a strict sense. (The true cardioid has a $y = 1 + \cos\theta$ characteristic. There is wider front-angle response in the true cardioid and a smaller response to the rear.)

Pressure-operated, moving-coil dynamic types of microphones such as the Western Electric 633A (Fig. 43) and the RCA 88A (Fig. 44) are used where small size, light weight, and portability are important. Although generally classed as nondirectional microphones, such microphones are nondirectional only for the lower frequencies; they become more and more directional as the frequency is increased and are quite directional above approximately 2000 cps. These microphones are about

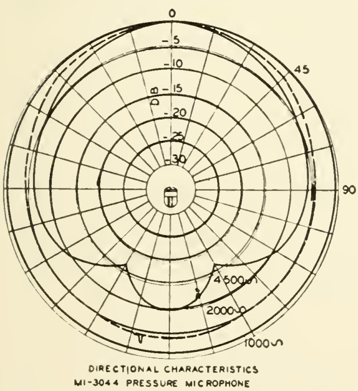


Fig. 44A. Direction-response characteristics of RCA MI-3044 microphone.

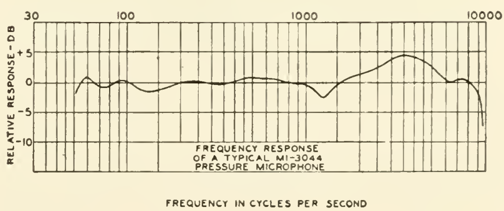


Fig. 44B. Response-frequency characteristic of typical MI-3044 microphone.

3.5 inches long and weigh about a pound. Western Electric supplies a detachable baffle for the 633A microphone that increases the directional effect at the higher frequencies (above 1000 cps) and increases the middle-high response (at 2500 cps) at the expense relatively of the higher frequency response (at 6500 cps). In practice, the directional characteristic of the pressure-operated microphone is something of a disadvantage because the slight turning of a speaker's head with respect to the axis of the microphone produces noticeable changes in recorded voice quality. This limits the mobility of actors on a set in the case of simultaneously recorded synchronized sound, and makes it difficult for a commentator reading script, in the case of post-synchronized recorded sound, because he must limit the shifting and twisting of his head as his eyes

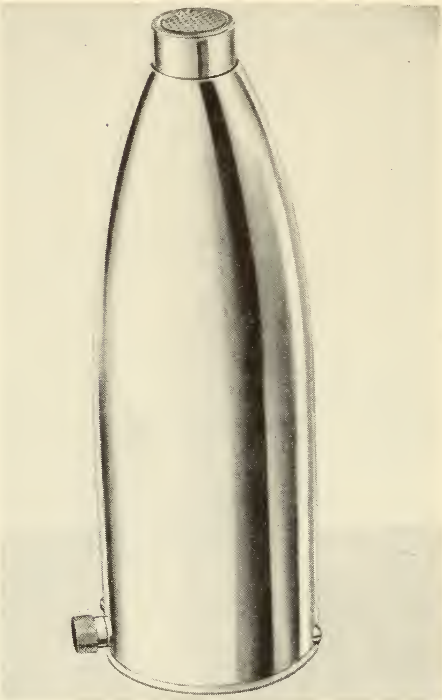


Fig. 45. Western Electric 640AA condenser microphone and RA-1095 amplifier. *Frequency characteristic:* Free-field response: see Figure 45A. *Output level:* Approximately 49.5 db below 1 volt (open circuit) per dyne/cm^2 with 200 volts d.-c. polarizing potential. *Output impedance:* Essentially that due to its capacitance which is approximately 50 mmf. to 60 mmf. *Operates into:* Grid circuit of closely associated vacuum tube amplifier (such as Western Electric RA-1095 amplifier). *Polarizing voltage:* 220 volts d.-c. maximum from well regulated quiet supply. (Caution: polarizing voltage exceeding 220 volts should not be applied as higher voltages may damage the instrument.) *Dimensions:* Cylindrical shape approximately 1″ diameter and 1″ long. *Weight:* Approximately 1½ ounces. *Mounting:* For optimum signal-to-noise the microphone should be closely associated with the first stage of amplification and preferably mounted in the structure containing this amplifier. *External connection:* The 640AA microphone is especially designed to mount on the RA-1095 amplifier. It has a spring mounted plunger and male base threads for providing connection to the amplifier. When associated with another type of amplifier, the microphone should be connected to the grid of the vacuum tube by means of a short, well-shielded, low capacitance lead to the center contact at rear of instrument. The cylindrical shell of the microphone should be connected to the grounded side of the grid circuit thereby serving as a shield for the inner components. *Protection:* Provided with a dust cap for each end of the cylinder when instrument is not in use.

RA-1095 Amplifier—Typical Electrical Characteristics

Frequency characteristic: See curve, Figure 45A (microphone and amplifier in combination). *Output level:* Approximately –29.5 dbm with the 640AA microphone in a sound field of 10 dynes/cm^2 or – 49.5 dbm in a 1 dyne/cm^2 sound field. *Signal-to-noise ratio:* Approximately 40 db at an output level of –49.5 dbm (0–15,000 cycle band). *Distortion:* Less than one percent at –3 dbm output level. *Operates from:* 640AA condenser microphone. *Output impedance:* Designed to be used with equipment having rated source impedance of 25–50 or 150–250 ohms. *Power supply:* Quiet sources required for both filament and plate power. (*Heater:* 6.3 volts, 150 milliamperes, direct current. *Plate:* 220 volts maximum, 3 milliamperes, direct current. Caution: Plate voltages exceeded 220 volts should not be applied when the 640 type microphone is attached, as higher voltages may damage the microphone). *Dimensions:* Approx. 7¾″ long, 2½″ diameter. *Weight:* Approx. 1¾ pounds. *External connections:* Through 6 prong socket in base of amplifier. (Use Cannon 6 hole female plug P6-11). *Mounting:* Suspend from socket cord or use shock mounting hanger to fit user's microphone boom or other suspension mounting.

instinctively jump from script to microphone during a recording. Because of the image spread that occurs on film—an effect which is quite serious for variable-area recording if films of other than best resolving power are used in other than the best developers—pressure-type microphones are likely to cause excessive or distorted recorded sibilants because of their comparatively "jagged" response-frequency characteristics even with relatively small deviations from the best in films and in processing. In the more obvious cases, either the "s" sounds are very annoying because the effect is like that of a very bad set of false teeth, or they may be distorted to the point where the "s" sounds are reproduced as "f's" or "th's" and even worse. While the use of a 5300 cycle low-pass filter (which is a part of the band-pass filter of range F that limits the frequency range to 110 to 5300 cps) may limit the distortion to an acceptable value on occasion, the substitution of one of the more expensive

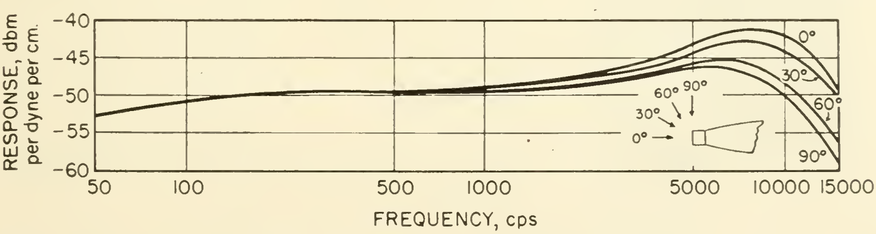


Fig. 45A. Typical free-field response curve of Western Electric 640AA. dbm equals db relative to a power level of 1 milliwatt in a resistive load corresponding to the nominal amplifier output impedance.

types of microphone such as a cardioid type will often eliminate this difficulty and, at the same time, result in recordings of somewhat lower recorded noise level and better smoothness.

For a number of years prior to World War II condenser microphones had been almost completely displaced by the pressure-operated moving coil microphones (such as those just described) despite the popularity of the condenser microphone some 15 years ago. Now it seems that the condenser microphone* can stage a comeback as the recent redesign in the Western Electric 640 AA (Fig. 45) overcomes many of the disadvantages of the earlier condenser microphones with regard to size, frequency characteristic, and certain maintenance difficulties. As the directional properties of a pressure-operated microphone depend upon the ratio of the diaphragm diameter to the wavelength, the reduction of the diameter

* Another recent design is the Altec-Lansing; this is even smaller.

to one inch has shifted the pressure-doubling peak of the microphone beyond 5000 cps from its former 3000 cps value; the performance is now so smooth and consistent that the microphone is very well suited to sound pressure measurement—for which it was originally designed. This microphone is customarily used with a Western Electric RA-1095 amplifier, a single-stage amplifier using a "door-knob" 382A Western Electric tube. The output transformer in the amplifier may be connected for 30–50 ohms

Fig. 46. RCA 44BX velocity microphone (ribbon microphone).

Specifications—Type KB-5A (for Sound Films)

Output level (at 1000 cycles when terminated into matched load)*: −55 db (0 db = 1 mw); −63 db (0 db = 6 mw). *Directional characteristic:* Bi-directional—figure 8 pattern (see Fig. 46A). *Frequency response:* 30–10,000 cycles (see Fig. 46B). *Output impedances:* 250 ohms and 50 ohms (connected for 250 ohms when shipped). *Dimensions:* Length, including hanger: 10½″; Width: 4¾″; Depth: 3⅜″; Weight, including hanger (unpacked): 8¼ lb. *Stock identification:* MI-3027-E.

Accessories

Suspension hanger: MI-4076-A. *Program stand:* MI-4090-A. *Boom stand:* MI-4094-B . *Announce stand:* MI-4058-C. *Cushion adaptor for stand mounting:* MI-3033-A. *Suspension mounting:* MI-3065.

impedance or for 200–250 ohms impedance; the output is some 25 db higher than unaided moving conductor microphones. When sound originates "head on," the response-frequency characteristic which shows a maximum output at 8000 cps has approximately the same response at 20,000 cps as at 1000 cps. The microphone and its associated amplifier weighs 1 3/4 pounds and is 7 3/4 inches long and 2 1/2 inches in maximum diameter; it requires 0.150 amperes at 6.3 volts for the heater of the electron tube and 180 volts at 3 milliamperes for plate supply for the

* Input sound pressure of 10 dynes per square centimeter.

electron tube. Polarizing voltage for operation of the condenser microphone is taken from the plate supply.

Velocity-Operated Microphones

Velocity-operated microphones such as the RCA 44BX (Fig. 46) are used where weight and size are less important than smoothness and fidelity. The diaphragm resonance of diaphragm-type microphones occurs in the middle of the speech range at about 800 cps for moving-coil microphones, or further up in the speech range between 3000 and 8000 cps for condenser microphones. The ribbon resonance, on the other hand, occurs below the speech range at 10 to 15 cps. The ribbon used is light, thin, and relatively short; the ribbon in the RCA 44BX microphone

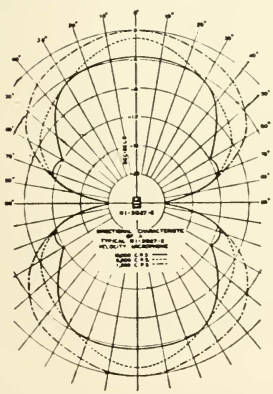


Fig. 46A. Direction-response characteristic of RCA MI-3027-E microphone.

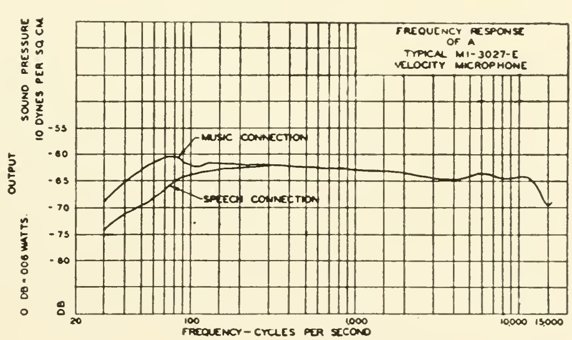


Fig. 46B. Response-frequency characteristic of typical RCA MI-3027-E microphone.

is a duralumin corrugated strip about 2 in. long, 3/16 in. wide, and about 0.0002 in. thick. The ribbon is suspended between poles of an Alnico permanent magnet, with the length of the ribbon perpendicular to—and its width in the plane of—the magnetic flux passing between the two magnet poles. The ends of the ribbon, across which the voltage appears from the movement of the ribbon in the magnetic field, are connected to a transformer whose output is connected to the output terminals provided for the microphone. Such a microphone is bidirectional; it picks up equally well from either of two opposite sides in a direction perpendicular to the plane of the ribbon. The microphone is directional for both low and high frequencies; for practical purposes the response may be con-

sidered proportional to the cosine of the angle between the plane of the ribbon and the direction of approach, with maximum response occurring normal to the plane of the ribbon. There is very little frequency discrimination with change in angle of incidence of the approaching sound; the directional characteristics of the ribbon microphone are quite uniform for all frequencies in its design range. The 44BX microphone is capable of substantial output to 20,000 cps; its weight is about 8 1/2 pounds and its length (including the cushion mounting) is about 12 inches.

As the energy response of the ribbon microphone to randomly reflected sound is but one-third that of a nondirectional microphone, it is possible to increase the distance between the sound source and the microphone for the same "quality" (ratio of direct sound to randomly reflected sound) as that obtained with a nondirectional microphone. The ribbon microphone is excellent for the recording of music because of its smoothness; it is also very good for the recording of speech—provided the speaker is at least 2 feet from the microphone. When the speaker-to-microphone distance is less than 2 feet, the recorded speech sounds unnatural and tubby; ordinarily no simple form of equalizing is capable of satisfactorily correcting for the deterioration in quality that results. Some RCA 44 type microphones are provided with a voice tap connection at the microphone terminal board; when the voice tap is connected, the response of the microphone is attenuated in the low-frequency range by some 6 db at 100 cps.

Cardioid Types of Microphones

For years designers have been trying to make a unidirectional microphone that is as small and light as the smaller pressure-operated microphones (about 3 inches long and weighing not more than 1 pound); such a microphone should have the sensitivity of a pressure-operated type such as the Western Electric 633A, it should pick up sound from one side only, and it should be equally directional for low and for high frequencies. Such a microphone would make it possible to discriminate against noise and extraneous sound such as camera noise that originate in a direction different from that of the sound source to be recorded; in addition, the ratio of the direct sound picked up by the microphone to the reflected sound could be increased, thereby materially improving the quality of the recording. Small size is desired because a microphone casts a shadow when it is used on an illuminated set, and the smaller the microphone, the smaller is the shadow. Light weight is desired because the micro-

phone is suspended on the end of a microphone boom; this is a long "fish pole" used to place the microphone in the best possible position in the sound field. Heavy microphones (such as the RCA 44BX ribbon type) require a heavy, complicated, clumsy, expensive boom that is often noisy. Controls, usually in the form of cranks, are provided at the boom tripod to permit twisting and tilting of the microphone while recording is in progress in order to "point" the microphone at the sound source. It is usually difficult to locate and to manipulate a large microphone so that its shadow does not appear in the picture and so that the noise from the cables, cranks, wheels, etc. of the boom are not picked up by the microphone. Not of least importance is that a "fancy" boom with a large number of controls needs several highly skilled personnel to run it, because of the close coordination required among the members of the sound-recording crew.

One of the earlier designs of cardioid microphones was the RCA 77A. Although its directional properties were something of an improvement over the bidirectional ribbon microphone, it was as large and about as heavy and thus did not overcome the size disadvantage and the weight disadvantage of the otherwise excellent ribbon microphone. The RCA 77A and the later designs, such as the RCA 77B, 77C, and 77D and the Western Electric 639A and 639B are in reality two mechanisms combined within a single housing—a pressure-actuated element and a velocity-actuated element. The unidirectional characteristic is obtained by electrically combining the nondirectional characteristic of the pressure-actuated element with the bidirectional characteristic of a separate velocity-actuated element.

The RCA 77B is one of the lightest and smallest of the unidirectional microphones of this kind; its weight is about 2 pounds and its length about 10 inches. Its front-to-back discrimination is about 20-to-1; its directional characteristic is quite uniform in front for low and high frequencies. At the rear, however, it is sharply directional in its pickup at high frequencies (at 8000 cps) where its response along the rear axis is 10 db less than its response along the front axis. The low-frequency pickup, however, is quite small at the rear.

The RCA 77C and the Western Electric 639A each have a switch in the microphone housing that permits selection of a ribbon, a dynamic, or a cardioid type of response merely by moving the switch setting. This is accomplished by utilizing only the appropriate parts of the microphone mechanism for energizing the microphone output terminals. Incidentally

there are important design differences between the Western Electric and the RCA products; the RCA microphone utilizes a thin ribbon for the bidirectional element and a second ribbon which is pressure-loaded for the pressure element; the Western Electric products use a relatively thick and stiff ribbon for the bidirectional element and a small diaphragm-actuated moving coil for the pressure-actuated element. The RCA 77C weighs 3 pounds and is 8 1/2 inches long; the Western Electric 639A weighs 3 1/4 pounds and is 7 1/2 inches long.

Fig. 47. Western Electric 639B cardioid microphone.

Specifications

Response-frequency characteristic: Essentially uniform from 40 to 10,000 cps. *Sensitivity:* Open circuit voltage 64 db below 1 volt per 10 dynes per square centimeter; equivalent to 84 db below 1 volt per 1 dyne per square centimeter. *Signal-to-noise Ratio:* 78 db above thermal agitation noise generated within the microphone for a signal of 10 dynes per square centimeter; 58 db for 1 dyne per square centimeter. *Directivity:* Six patterns—R, D, C, 1, 2, and 3 selectable through a six-position screw-driver-operated switch. At the angle of minimum response, the average discrimination with respect to the 0° response is 20 db over the range from 40 to 10,000 cps. *Impedance:* Varies somewhat throughout the frequency range; average value is 40 ohms. It is intended for use with equipment haveing a rated source impedance from 25 to 50 ohms. *Power output level:* −56 dbm for 10 dynes per square centimeter, −76 dbm for 1 dyne per square centimeter, when the microphone is terminated with a resistance equal to its internal impedance. Approximately 10 dynes per square centimeter sound pressure is produced at conversational speech level three feet from a microphone. *Dimensions and weight:* Height 7 1/2″ including the plug terminal; Length 4 7/16″; Width 3 7/16″; Weight 3 1/4 lbs.

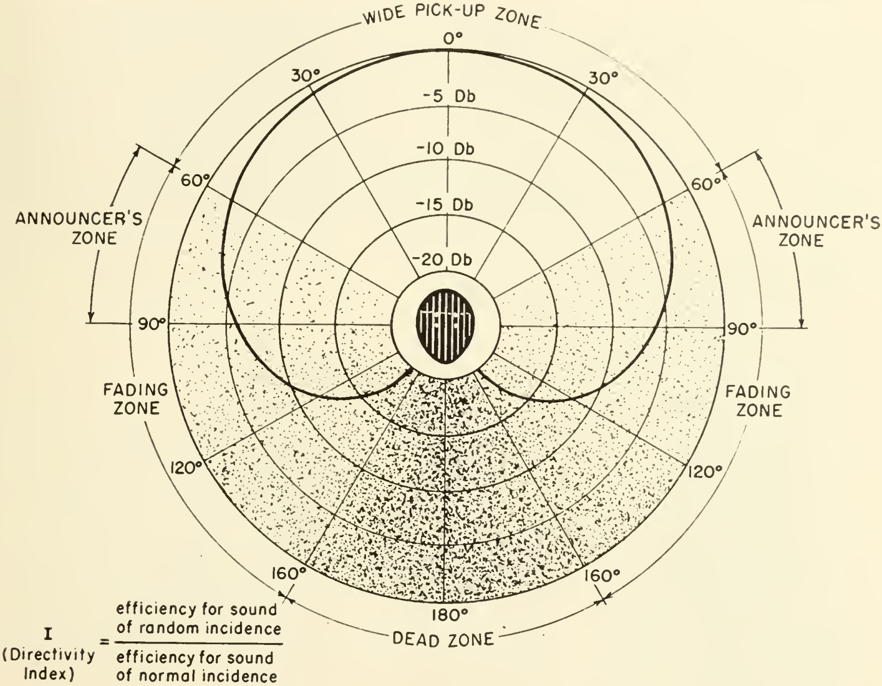


Fig. 47A. Directional response cardioid microphone.

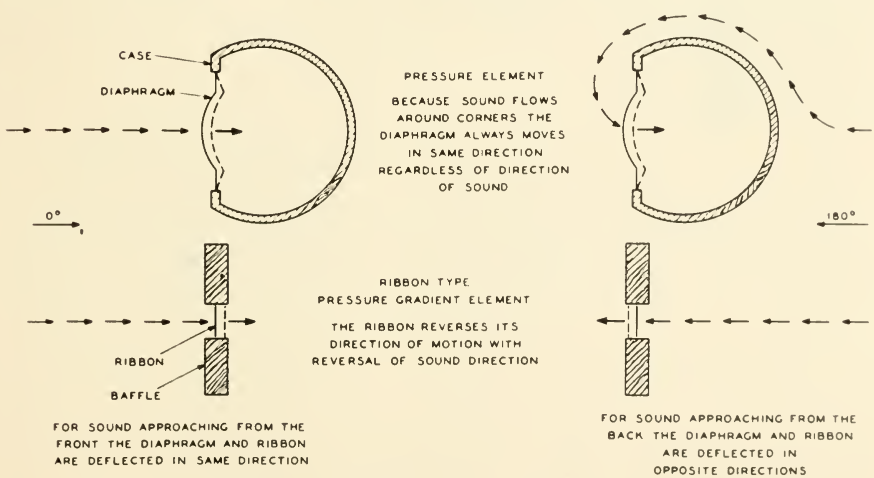


Fig. 47B. Schematic illustration of cardioid directional microphone.

The Western Electric 639B (Fig. 47) and RCA 77D (Fig. 48) not only provide a choice of the three directional characteristics provided for the Western Electric 639A and the RCA 77C, but also provide a choice of three additional directional characteristics that alter in relative amounts the contributions of the velocity-actuated and pressure-actuated elements. The size and weight of the 639B is about the same as the 639A; that of the 77C is about the same as the 77D.

Specifications

Directional characteristic (adjustable): Bi-directional, uni-directional and non-directional. *Output impedances (tapped transformer):* 50/250/600 ohms. *Effective output level:* −57 dbm*. *Hum pickup level:* -118 dbm**. *Frequency response:* See Fig. 48B. *Finish:* Satin chrome and umber gray. *Mounting:* ½″ pipe thread. *Dimensions, overall:* Height 11½″; Width 3¾″; Depth 2½″; *Weight (unpacked inluding mountings):* 3 lbs. *Cable (MI-43 3 conductor shielded):* 30′ less plug. *Stock identification:* MI-4045-A.

Accessories

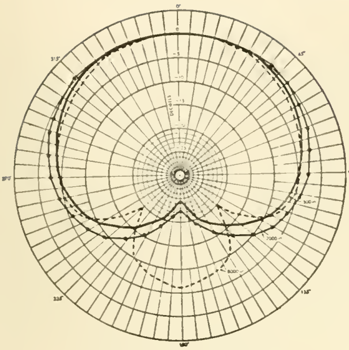
Microphone plug: MI-4630-B. *Protective cloth bag:* MI-4087.

Fig. 48. RCA 77D cardioid microphone (polydirectional—MI-4045-A).

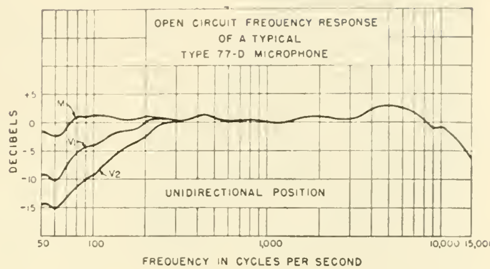
One manufacturer, Shure Brothers of Chicago, has been marketing a unidirectional microphone, #556 (Figs. 49 and 49A), with but a single pressure-actuated diaphragm-type element. In this design, an acoustical network is used with the single moving coil element to provide the unidirectional characteristic. This design has merit because of its simplicity. The concept of the single element with appropriate electrical and acoustical networks has been applied to velocity-actuated elements in the RCA MI-10,001 microphone shown in Figures 49B, 49C, and 49D. With sim-

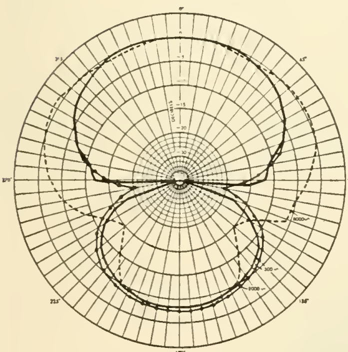
* Referred to one milliwatt and a sound pressure of 10 dynes/cm^2.

** Level referred to a hum field of 1×10^{-3} gauss.

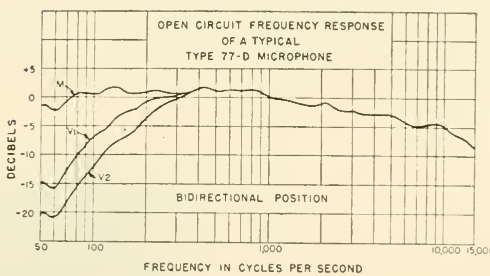


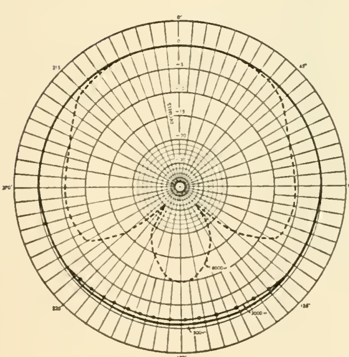
Uni-Directional Position





Bi-Directional Position





Non-Directional Position

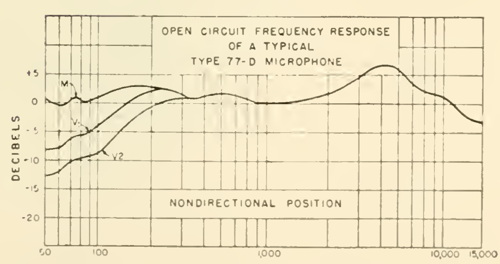


Fig. 48A. Directional response characteristics of RCA 77D microphone.

Fig. 48B. Response-frequency characteristics of RCA 77D microphone.

1000 cps Response

Model 556 "L" position:	
Open circuit voltage level	−84.1 db. *
Loaded with 40 ohms	−90.1 db. *
Power level into 40 ohms	−56.1 db. **
Model 556 "M" position:	
Open circuit voltage level	−76.8 db. *
Loaded with 250 ohms	−82.8 db. *
Power level into 250 ohms	−56.8 db. **
Model 556 "H" position:	
Open circuit voltage level	−57.5 db. *
Loaded with 100,000 ohms	−60.1 db. *

Recommended Load Impedance

Model 556 "L" position 30–50 ohms.
Model 556 "M" position 150–250 ohms.
Model 556 "H" position 100,000 ohms or more.

Fig. 49. Shure #556 Super-cardioid microphone. This microphone uses a single generating mechanism of the pressure type with an acoustic phase inverter to obtain its directional characteristic. * 0 db. = 1 volt per dyne per sq. cm. ** 0 db. = 1 milliwatt with 10 dynes per sq. cm.

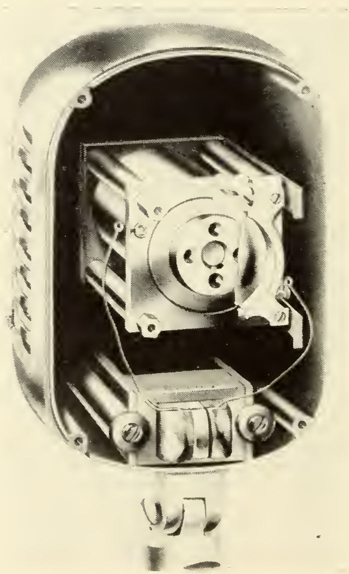


Fig. 49A. Shure #556 microphone—cut-away view.

Specifications

Output impedance: 30, 150, 250 ohms. Connected for 250 ohms when shipped. *Load impedance:* Open circuit (unterminated transformer). *Effective output level at 1000 cycles:* – 51 dbm at 150 and 250 ohm output impedance; – 49 dbm at 30 ohm output impedance. *Frequency response:* See Figure 49D. *Directional characteristic:* See Figure 49C. *Mounting:* A suitable resilient mounting is essential. RCA MI-10055 microphone hanger is designed for this application. *External connection:* Type "P" 3-pin Cannon Connector. *Finish:* Flat two-tone umber-grey. *Dimensions:* Length 8″; Width 3″; Depth 3½″; Weight (less suspension mounting) 2$\frac{13}{16}$ pounds. *Stock identification, microphone:* MI-10001. *Stock identification, suspension mounting:* MI-10055.

Fig. 49B. RCA unidirectional microphone (MI-10,001) with resilient mounting microphone hanger (MI-10,055).

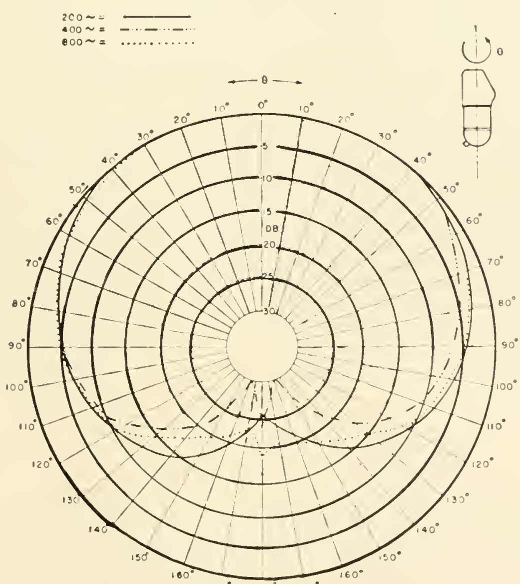


Fig. 49C. Directional response characteristics of RCA MI-10,001 microphone.

plified designs of this general nature available, improved performance and a reduction in manufacturing costs should be possible. 16-mm-equipment users would do well to watch the development trend very closely, since the microphone often holds the key to the excellence of the recorded sound.

Almost all up-to-date microphones are of low connection impedance, either 50 ohms or 250 ohms, and are characterized by a conductor moving in a magnetic field of high flux density provided by a light yet efficient magnet. (Alnico 5 is a typical magnet material.) The trend toward smaller and lighter microphones will demand improved materials and still closer tolerances in manufacture. Considerable improvement in ruggedness should likewise be expected as a result of the experience gained during World War II with intercommunication microphones and

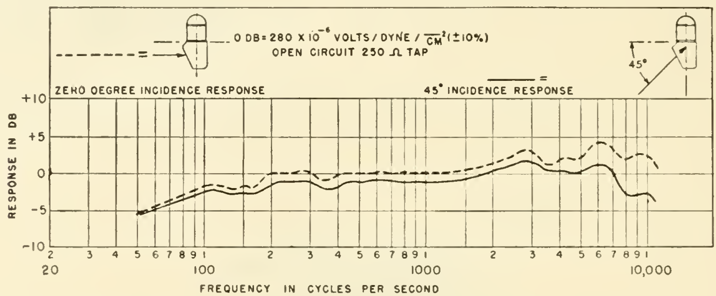


Fig. 49D. Response-frequency characteristics of RCA MI-10,001 microphone.

electrical instruments, such as photoelectric exposure meters. It should be mentioned that there is a standardization movement in the direction of making the connection impedance 150 ohms for all microphones. This impedance has also been proposed as the standard connection impedance for other low- and medium-level circuits. At the time of writing, however, few commercial microphones with the proposed connection impedance are being supplied regularly.

Highly Directional Microphones

Although not ordinarily suited to sound-film recording, this group of microphones is entitled to passing mention. Typical of the group are the parabolic reflector microphone and the line microphone.

A typical parabolic reflector microphone consists of a shallow, dish-like, approximately parabolic reflector about 3 feet in diameter with a pressure-type microphone located at the approximate focus of the para-

bola. The directivity of this microphone is practically nil at 200 cps and increases with increasing frequency—becoming very sharp at 8000 cps. Although sound can be picked up over a distance of 50 to 100 feet with such a microphone, the variation of directivity with frequency causes serious changes in quality to occur when the location of the sound source is shifted during recording with respect to the axis of the parabola. Since most dialogue recording for sound films usually involves movement of the actors, parabolic reflector microphones are rarely used today.

The line microphone is essentially a bundle of small tubes of different length, open at one end and coupled at the other end to a pressure-type microphone. A line microphone can be designed that does overcome to some degree the serious azimuth-frequency discrimination of the parabolic reflector microphone; such a microphone is complex and is neither small in size nor light in weight. In use, a line microphone is "aimed" at a sound source.

Other Forms of Microphones

Many other forms of microphones have been proposed and used. Of these, one group that is commercially and scientifically important although little used in 16-mm sound recording is the crystal microphone. This microphone uses a Rochelle salt crystal to convert the sound energy into electrical potentials; a voltage is produced by mechanically deforming a cemented assembly. Generally speaking, crystal microphones—whether diaphragm-actuated, sound-cell actuated, etc.—are used very little commercially in 16-mm sound recording because of the unfavorable temperature-response characteristics of the Rochelle salt crystal. The crystal becomes permanently damaged when the temperature exceeds 140°F. Crystals that are not hermetically sealed—and most are not —show a continual exchange of moisture with the surrounding atmosphere when the relative humidity and the temperature of the atmosphere changes. With each such change in temperature and in moisture occurs a change in response characteristics.

Microphone Equalizers

It should be apparent that it is not possible merely to substitute one type of microphone for another without making some allowance for the differences in response-frequency characteristic from one microphone to another. Fortunately, the differences between different microphones of the same make and type are often sufficiently small that no provision need

ordinarily be made for them. Thus a microphone equalizer is intended to compensate primarily for differences in types of microphones rather than for individual differences between different microphones of the same make and model.

In addition to the microphone equalizer, a dialogue equalizer is usually associated with a microphone together with a high-pass filter to limit the amount of low-frequency noise transmitted, and with a low-pass filter to limit the amount of high-frequency noise transmitted. For convenience and for reducing the cost, all these equalizers may be combined and made up as a single network. As the output of a microphone is quite low in level, the introduction of an equalizer directly into the microphone output circuit would risk the introduction of consider-

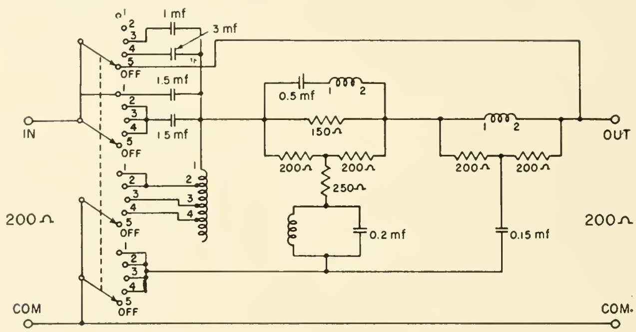


Fig. 50. Correction equalizer for Western Electric RA 1142 microphone. This equalizer is also suitable for the Western Electric 639A and 639B microphones, and for the RCA 77B, 77C, and 77D microphones.

able hum and noise and would require magnetic shielding that is very expensive and probably inadequate despite its high cost. For this reason such equalizers are customarily designed to operate in the output circuit of the preamplifier following the microphone where the signal level is higher by 30 db or more than it is directly at the microphone output. At this higher signal level, the reduction in signal-to-noise ratio resulting from the use of the equalizer should not be serious for a well-designed and well-shielded unit; the increase in distortion and noise should be almost inaudible on even the very best monitor speaker system.

Figure 50 shows a correction equalizer designed for the Western Electric RA-1142 microphone. This equalizer may be used with the Western Electric 639 types or with the RCA 77B, 77C, or 77D. As the re-

sponse of the RA-1142 cardioid microphone is quite flat and smooth throughout the frequency range, the correction equalizer shown is primarily intended as a voice-effort equalizer. As is the case with velocity microphones, cardioid microphones require that a speaker be no closer to the microphone than about 2 feet; if the distance should be less, the recorded speech will be unnatural and tubby.

All microphones described have sufficient high-frequency response for good recording; all have substantial response beyond 10,000 cps. Should high-fidelity recording be practicable, these microphones are capable of providing it if used properly and if associated with suitable equalizers.

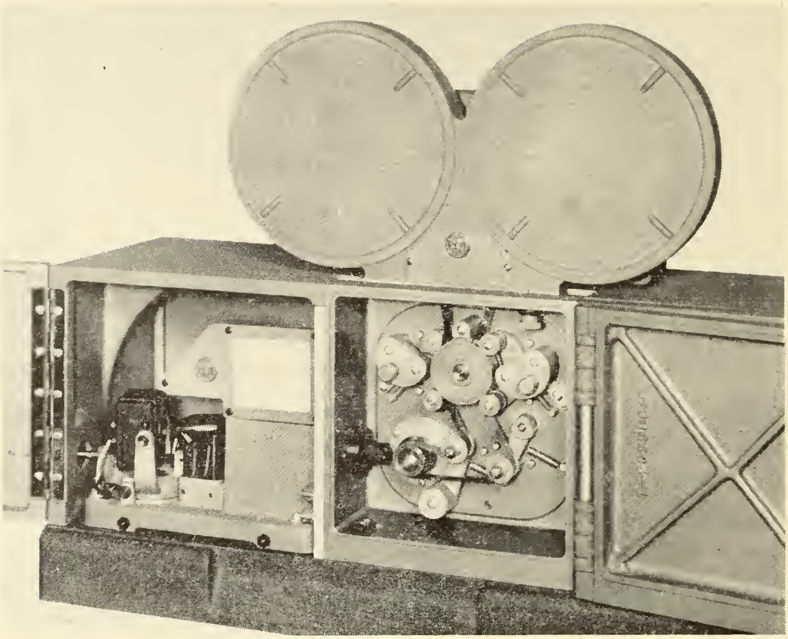
The Sound-Recording Machine

Since the amplifiers and their equalizers and adjuncts are intended to correct for the transmission losses in all other parts of the recording and reproducing system, it is well to consider the recording machine before discussing the characteristics of the amplifier equipment.

In the last decade the sound-recording machine has seen major changes. The film-transport system—although still simple—has been improved to the point where flutter and wows audible to the average ear are practically unknown. No commercial 16-mm sound-recording machine now uses a rigidly coupled film-driven flywheel; all machines use more complex filtering arrangements and are manufactured to surprisingly close tolerances. To take advantage of the excellence of these machines, film manufacturers now supply sound-recording film of high resolving power (150 lines per mm) on base material that can be guaranteed to have less than 0.5% shrinkage (Eastman 5372).

Film Transport

The RCA PR32 16-mm sound-recording machine (Fig. 51) has a film-transport mechanism that is a modification of the RCA 35-mm machines. The film moves past the exposure light beam on the surface of a smooth drum; on the other end of the shaft which carries the drum is a large flywheel. The film transport system may be described briefly as a tight loop film path using a solid type flywheel on the drum shaft. This basic design, although historically quite old, was pioneered commercially about a decade ago by Maurer in the Model D Sound Recording Machine. Its performance with regard to flutter is surprisingly good; it represents a simple yet effective solution to the very difficult design problems that must be solved for a machine that is to be designed for satisfactory opera-



Specifications

Finish: Light umber gray wrinkle, dark umber gray wrinkle trim. *Length:* 23¾″. *Depth:* 9″. *Depth:* 9″. *Height:* 18″ (incl. magazine). *Weight:* 62½ lbs. *Optical system:* MI-10383—16 mm. *Standard track types:* Bilateral negative (a.-c. or d.-c. lamp supply); Bilateral direct positive (d.-c. lamp supply only). *GNR system:* Biased galvanometer. *GNR current required:* 20 ma. (approx.). *Audio input required:* $+24 \pm 1$ dbm for 100% modulation. *Exposure lamp:* MI-10674 (10.5 volt, 7.8 amp., s. c. prefocused base, curved filament, T-8 bulb). *Flutter:* Total flutter less than 0.15%. *Film weave:* Less than 0.001″. *Reversing switch:* Synchronous motor drive only. *Exposure lamp ammeter:* 0–8 ampere a.-c. or 5–8 ampere d.-c. (stk. 901479). *Power supply:* a. Drive motor power supply as required by selected motor; b. Exposure lamp 14 volts, 8 amperes. *Lubrication:* RCA #25367 light recorder oil, light grease for gears and driving chain.

Stock Identification

110 v., 60 cy., 1 ph.—synchronous motor, 400 ft. take-up: MI-10310. 110 v., 50 cy., 1 ph.—synchronous motor, 400 ft. take-up: MI-10311. 200 v., 60 cy., 3 ph.—synchronous motor, MI-10679, 1200 ft. take-up: MI-10322. 220 v., 60 cy., 3 ph.—synchronous motor, 400 ft. take-up: MI-10323. 220 v., 60 cy., 3 ph.—a.-c. or 96 v. d.-c. motor (multi-duty), 400 ft. take-up: MI-10331.

Accessories

Focusing microscope: MI-10729. *Film magazine, 400 ft.:* MI-10741. *Galvanometer:* MI-10717. *Canvas dust cover:* MI-10739. *Film magazine, 1200 ft. (MI-10322 only):* MI-10770.

Fig. 51. RCA 16-mm sound film recorder—type PR32.

tion in either the left-to-right or the right-to-left directions. Such operation is essential—and is so recognized—to cope effectively with the problem of emulsion position in contact-printed release prints. The flutter of the RCA PR-32 is rated at less than 0.15%.

In the Maurer sound-recording machine (Fig. 52) the film also moves past the exposure light beam on the surface of a smooth drum; on the other end of the shaft that carries the drum is a large flywheel, as in the RCA machine. The filtering of motion of the Maurer machine is in two stages; the drive gear is coupled to the flywheel hub by resilient felt or similar bushings, and the flywheel hub is coupled to the flywheel itself by an oil film. Flutter of the Maurer machine is rated at less than 0.05%. This new machine has a larger flywheel and a larger drum than its excellent predecessor, the Model D machine; the flutter has been reduced to about one-half its previous value. The hydraulically-coupled flywheel arrangement was pioneered by Kellogg of RCA. Western Electric machines of current manufacture also have an excellent transport system of a generically similar type.

When well maintained, both the RCA and the Maurer recording machines have excellent film motion; it is far superior to the film motion found in any commercial sound projector. Flutter may be checked readily by recording a 3000-cps tone at constant amplitude, developing the film, and measuring the flutter with an RCA or Western Electric flutter bridge or equivalent with the film being reproduced on a special "grindstone" type of test reproducer. Recording equipment manufacturers customarily make such tests in a routine manner when sound-recording machines are manufactured. The machine used for reproducing is usually made with great mechanical precision; one type commercially used has a 60-pound flywheel coupled directly to a drum that revolves twice or less per second; the drum has an eccentricity of only about one-tenth of a thousandth of an inch. Needless to say a flutter film recorded on such a grindstone and reproduced on such a grindstone has so little flutter recorded in it that it is possible to make an "A-B" test by switching quickly from an oscillator to the film without observing aurally any difference in film motion introduced as flutter. Testing the smoothness of motion of a recording machine is customarily made in accordance with American Standard Z22.43-1946, "3000-Cycle Flutter Test Film." Much attention has been given to the study of uniformity of film motion; the machines made by major film recording machine manufacturers may be relied on to be satisfactory in this respect. In practice,

the quality of recording with regard to film motion depends more upon the care in manufacture and the care in maintenance and oiling of the particular machine than upon advertised design features. Periodic check

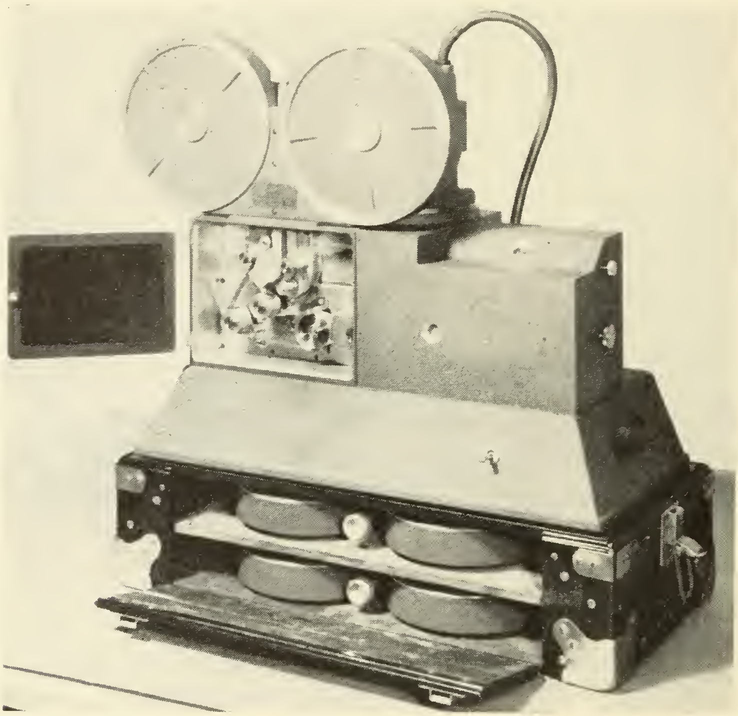


Fig. 52. Maurer 16-mm sound recording machine. (Fitted to the lower half of its carrying case.) *Magazines:* 400 ft size shown, 1200 ft size can be furnished. (The latter is used frequently for television.) *Motor drive:* Single phase 117 v. 60 cycle synchronous. Other types can be supplied as needed. *Propulsion direction:* The machine can propel film from either left to right or from right to left; the changeover is made by snapping a motor reversing switch. *Sound track forms:* Variable area—either negative or direct positive variable density negative. *Noise reduction:* Electrical bias of the galvanometer. This machine is designed to be energized from the ''recorder'' receptacle of the amplifier shown in Figure 63. Noise reduction and compression (fixed) are provided in addition to the audio signal.

of any machine for film motion is good operations' practice. A rough check may be made by observing with a microscope the motion of the sprocket holes of the film at the drum or other index while illuminated from a stroboscopic light source such as a General Radio Strobotac.

Film Guiding

Theoretically, when a film is guided in a sound recorder, it should move with absolutely uniform velocity in a fixed plane past the exposing light beam; it should be properly located with respect to dimensions in its relation to the light beam, moving without side weave. By moving in such a manner only the sound represented by the light beam variations will be recorded. If the plane of the film is not fixed, and the film moves in a direction along the optical axis, there will be an in-and-out-of-focus effect produced, since the depth of focus of the objective lens is usually small. If the plane of the film is not fixed, and the film moves in a direction perpendicular to the optical axis, small variations in distortion may occur due to the slight nonuniformity of the intensity of the exposure light beam and due to the slight nonuniformity of the sensitivity of the film. Large variations in distortion may occur if there is excessive weave, since the tops of the recorded wave peaks may be cut off when the print from the film is run through a sound projector.

As in the sound projector, the design engineer is faced with a dilemma, since the requirements for ideal film motion and the requirements for ideal film guiding are mutually contradictory in a good sound-recording machine. For accurately guiding the film with respect to the scanning beam, the film guide should be placed where the light beam impinges upon the film. For best motion, the film guide should be placed as far away as possible from the point where the light beam impinges upon the film. The result actually achieved represents the success of the chosen compromise of the design engineer; it is measured by the amount of flutter and by the amount of weave or misplacement present in the film.

35-mm sound recorders have been designed to propel film in only one direction; 16-mm machines, which recognize the commercial need for the recording at will of sound records for either standard or nonstandard emulsion position, are designed to propel film through the machine in either direction. In machines that provide for guiding in only one direction, a guide located ahead of the recording drum represents, theoretically, a good design compromise. Inasmuch as the 16-mm film is propelled by a single row of sprocket holes, propulsion thrust occurs which acts in the manner of a lateral-pressure edge guide. In practice, this design can be relied upon to guide satisfactorily when the machine is up to speed and running smoothly; track location may be inaccurate when the film is accelerating or decelerating. Appreciable difficulty in track

location will be encountered if the edge-guide roller bearings are not kept scrupulously clean and properly lubricated.

It is apparent that with 16-mm machines such an edge-guiding arrangement is unsuitable, since the film must be guided regardless of the direction of travel through the machine. Because of this the edge guides on the Maurer machine are located symmetrically on either side of the translation point on the recording drum. To reduce the motion-disturbing effects of edge friction and for the sake of simplicity, Maurer has chosen to use a "channel-type" guide in preference to an "edge-pressure" guide. In general, a channel-type guide is satisfactory when the width of the guide is but slightly larger than the widest film to be encountered, and when the length of the guide channel is large compared with the film width. Although, theoretically, the film may "wobble about" between the two guiding limits, the amount of friction introduced in practice is sufficient to damp out most oscillatory side motion. The "drift" in track location during the "settling-down" interval when the machine is coming up to speed is quite small in the Maurer design compared with 35-mm RCA design. Deterioration in film motion resulting from guiding at the translation point is so small that it is difficult to measure; the penalty paid for this form of edge guiding is a slight difference (about 0.001 in.) in track location between propulsion in one direction as compared with propulsion in the other direction. It is possible that the track-location difference could be reduced if all film manufactured were slit more accurately for width; inaccurate slitting is more likely to occur on certain non-American-made film than upon film made by the major American film manufacturers. The dimensional accuracy and dimensional stability of such films as EK 5372 are to be admired by sound-recording machine designers.

The Light Modulator

The light modulator of a sound recording optical system is a device that transfers power from an electrical system into movement or into intensity change of a light beam of a character than can produce a sound film record when these light variations are transmitted through the optical system to the film. There are several common types of light modulators in use.

(*1*) A string oscillograph type of galvanometer—such as the Einthoven or the Duddell—in which a current passing through a conductor loop upon which a small mirror is cemented causes the mirror to twist due to the reaction of current upon the

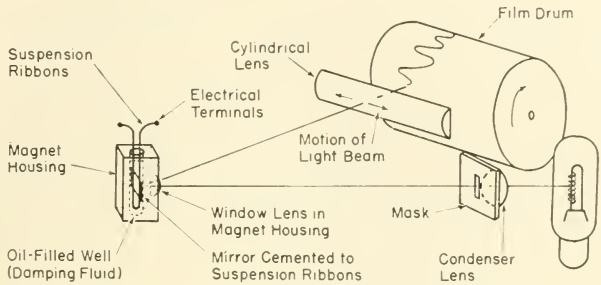


Fig. 53. Duddell oscillograph—optical system arrangement. This instrument has been familiar to electrical engineers for some 50 years. The electrical terminals are at the top of the ribbon. The ribbon is a continuous piece from top to bottom and back again; this results in opposite directions of current flow in the two parts when a potential is applied to the terminals. The current causes a twisting of the cemented mirror due to its reaction upon the strong and uniform magnetic field surrounding the ribbons. The ribbon and mirror assembly is immersed in a fluid such as mineral oil to effect mechanical damping.

Source impedance (must be resistive): 600 ohms. *Bias coil d.-c. resistance:* 180 ohms ± 10%. *Sensitivity (modulation):* +26 dbm ± 1 db for 100% modulation at 1000 cycles. *Bias current required:* 25 to 30 ma. *Frequency response (referred to 1000-cycle response):* ± 0.5 db from 100 to 5000 cycles; ± 1.0 db from 5000 to 9000 cycles. *Distortion (at 100% modulation):* Total harmonic distortion not greater than 1.0%. *Phasing:* Upward deflection of the light image will be obtained with d.-c. applied to the modulation and bias winding of polarity indicated at the terminals. *Important: Recorders other than those designed with the MI-10751 galvanometer as a companion item require changes in the input circuit before the deluxe galvanometer may be used.*

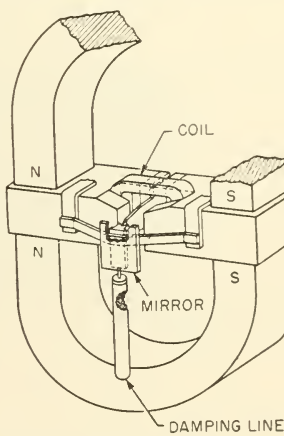


Fig. 54. Dry galvanometer—cut-away view (RCA film recording galvanometer MI-10751).

magnetic field in which the conductor is located (Fig. 53). The light beam reflected from the mirror moves in accordance with the current applied to the conductor. Ordinarily, the conductor is stretched to a point not far below the elastic limit of the conductor strip; a common conductor material is molybdenum. The magnetic field is customarily provided by a permanent magnet (*e.g.*, Alnico 5). The mirror may be a first-surface square mirror 0.050 in. square. The assembly is immersed in oil for damping; the resonance frequency of the assembly is customarily about 10,000 cps. This type of galvanometer is the finest ever devised for obtaining freedom from distortion. The changes in temperature of the damping fluid cause undesirable changes

in damping due to the changes in fluid viscosity. The oil-damped galvanometer was widely used in the United States prior to 1933 for RCA equipment for variable area; it was most widely used in Germany after 1933.

(*2*) A dry galvanometer—an iron armature is located in a magnetic field and is caused to move by the application of the electrical signal to a coil wound on the field poles of the magnet (Fig. 54). The construction of the dry galvanometer is theoretically quite similar to that of electromagnetic phonograph pickups with high armature stiffness; one design (RCA) used the mechanical advantage of leverage to increase the motion of a relatively large mirror mechanically connected to the armature by thin flat metallic strips, other designs (Maurer and Western Electric) have a smaller mirror cemented directly to the armature. Although the early dry galvanometers

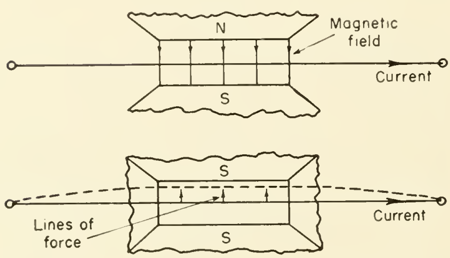


Fig. 55. Diagrammatic sketch showing how light valve string moves under influence of audio current.

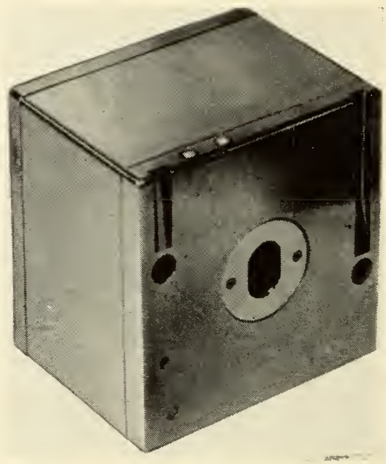


Fig. 55A. Modern Western Electric light valve.

were of poor fidelity, modern dry galvanometers are of good fidelity. There are distinctive design differences in the damping arrangements used by different manufacturers. The freedom from distortion of a particular light modulator depends far more upon the choice of suitable materials and upon the care taken in galvanometer manufacture than upon theoretical considerations. Dry galvanometers have displaced string oscillograph galvanometers almost entirely in the United States; they are widely used for variable-area sound recording.

(*3*) A light valve—a pair of "strings" that are caused to move toward and away from one another when a signal current is passed through them, the signal current reacting upon a magnetic field provided by a permanent magnet (Fig. 55). The strings of a light valve—also called ribbons—are flat metallic strips made of molybdenum or other metal of high tensile strength. The light valve is the modulator furnished by Western Electric; it is usually associated with variable-density recording. The movement of the ribbons of a light valve changes the amount of light transmitted between them. Strings always have high tensile strength and low mass.

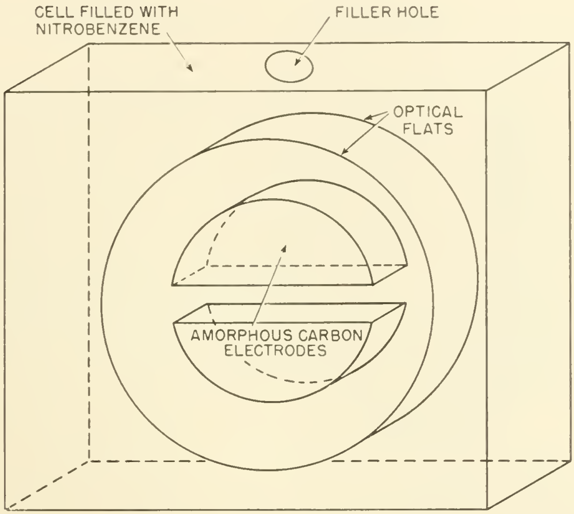


Fig. 56. Kerr (Karolus) cell.

Fig. 57. Fox-case movietone aeolight—a sound recording glow lamp. Glow lamps are rarely used in 16-mm recording today; they have given way to the dry galvanometer and to the light valve.

(*4*) A Kerr (Karolus) cell—the application of signal currents to its plates causes a change in the amount of polarized light transmitted through the cell because of a twist in the plane of polarization (Fig. 56). Nitrobenzene is the fluid commonly used as the medium. This type of light modulator was ordinarily associated with variable-density recording and is very little used today.

(*5*) A glow lamp—the application of signal current to a glow discharge lamp of suitable type causes a change in the intensity of the glow (Fig. 57). When the light is transmitted through a suitable optical system, a variable-density record is produced. This type of light modulator is little used today; ''flashover'' of the lamp usually changes the lamp output seriously, making accurate exposure control difficult. By appropriate optical design, any of the foregoing modulators may be used to provide either variable-density or variable-area recording. In the past, light valves were ordinarily associated with variable-density recording and galvanometers were associ-

ated with variable-area recording. Recently, however, both Western Electric and RCA make either form of recording available.

Measuring the distortion of a light modulator is a difficult matter, since the modulator would have to be removed from its associated optical system. Ordinarily, the single-frequency distortion at full amplitude at the frequency of maximum distortion can be kept under 2% in good commercial designs. So far little data has been published by manufacturers concerning distortion and its measurement in their light modulators, or, for that matter, to be expected in their complete recording systems. Intermodulation tests for studying the distortion characteristics of variable-density recording systems (American Standard Z22.51-1946) and cross-modulation tests for variable-area systems (American War Standard Z22.52-1946) have no doubt already been applied to the

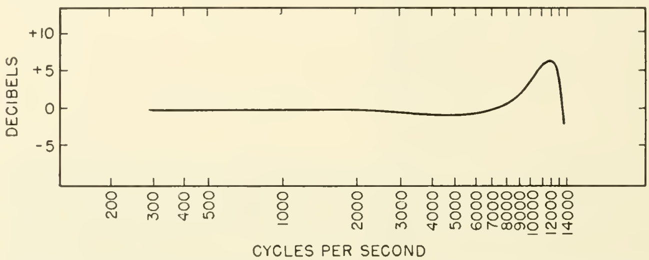


Fig. 58. Response-frequency characteristic of galvanometer used in Maurer sound recording machine of Figure 52.

study of light modulators and to their testing just as they have been applied in the study of distortion arising from film processing. This subject will no doubt receive much attention in the future.

Ordinarily it is not practicable for a user to remove a light modulator from its machine for the checking of its distortion; the difficulties encountered in readjusting the machine for correct optical and mechanical alignment in reassembly are almost insurmountable for the ordinary user because of the need for highly specialized alignment test techniques and equipment. The most practicable procedure is to test the sound-recording machine as a complete unit by recording on film whatever tests are necessary; the film should be of the same emulsion number and lot number as that used for production recording. A great deal can be learned by the inspection of such developed film as viewed under a microscope.

The trend in light-modulator design is toward higher primary-resonance frequencies. The new Maurer machine has a tuning point for its

Fig. 59. Bilateral variable-area sound track—unbiased negative and print. Vertical motion of the triangular recording light beam across the slit provides modulation of the track.

modulator at 12,000 cps (Fig. 58); for most purposes (such as for recording within range F or for ranges of more limited fidelity), the light modulator characteristics may be considered quite flat in the working range. Modulators made by other manufacturers, such as RCA and Western Electric, are also flat within range F; however, the tuning point, its amplitude, and the "sharpness" of tuning are all somewhat different, reflecting the different compromises of the designers.

The Optical System

The early optical systems for variable-area recording were designed to provide a sound negative of the unilateral unbiased type such as that shown in Figure 31. In the search for better fidelity, it was found that the unilateral form of sound track was not the most advantageous with regard to noise and distortion; better results were obtained with the

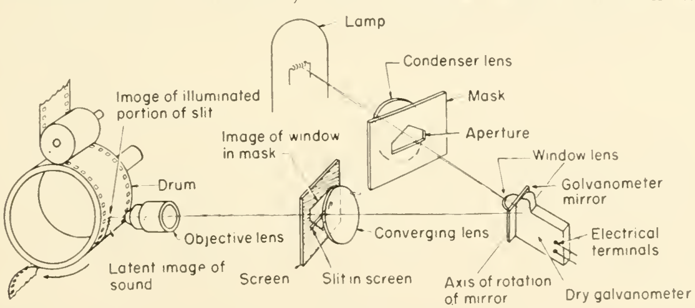


Fig. 60. General arrangement of typical optical system for producing bilateral variable-area sound track.

bilateral form as shown in Figure 59. The general arrangement of an optical system to accomplish this is shown in Figure 60.

The Slit and Its Effects. Ideally, sound is recorded and reproduced with a pencil of light that has—figuratively speaking—a very fine point. Ideally also, the film upon which the light beam acts is made up of sensitized particles that are also very fine. In addition, the light slit or pencil edge (similar to the flat edge of a carpenter's pencil) is located exactly at right angles with respect to the direction of travel of the film both in recording and in reproducing.

Unfortunately, these idealized conditions are not met in practice. The light slit or aperture has finite size and is not infinitely small. It is not located exactly at right angles to the direction of travel of the film in either the recording machine or in the sound projector. Also, the film structure is not infinitely fine, since the sensitized particles are finite in size.

In recording it is, of course, necessary to transmit sufficient light through the optical system to provide adequate exposure of the film. As the effective slit size is made smaller, the amount of light that can be transmitted through the optical system becomes smaller. Thus, the design problem is a compromise between the amount of exposure available and the slit width; to achieve good exposure with a sufficiently small width of slit requires design ingenuity—and increased cost. In recording, a relatively wide slit (such as 0.001 in.) causes both high-frequency loss and serious harmonic distortion; in practice, the distortion is the limiting factor because of the very objectionable quality of the sound that results.

In reproducing, a relatively wide slit causes primarily high-frequency loss and some harmonic distortion. Generally speaking, most 16-mm sound projectors have used slits that are too wide to permit good sound reproduction.

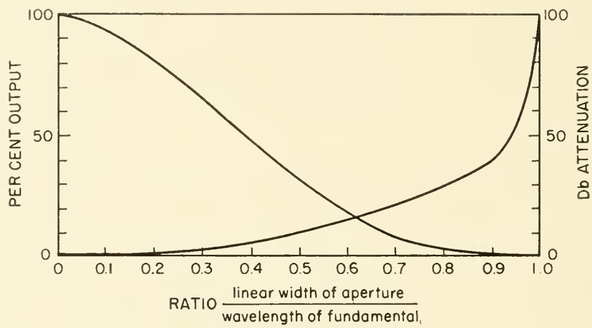
Slit tilt (or azimuth error as it is often called—deviation of the slit from exact perpendicularity to the direction of travel of the film) introduces really serious harmonic distortion in both recording and reproduction. For a particular slit tilt, the percentage of distortion climbs rapidly as the recorded frequency increases. In general, the azimuth error in recording machines is of a much lower order than the error in sound projectors; in modern recording machines, such as RCA, Western Electric, and Maurer, azimuth errors are quite small. In some sound projectors it is not uncommon to find a slit tilt of the order of one degree

and no provision for readily adjusting and correcting it. The error may vary appreciably from one projector to another and from one make to another; in general, machines with better sound optics are usually adjusted for azimuth more accurately than machines with poorer optics because increases in the high-frequency response of a projector markedly reveals azimuth deviation errors as harsh distortion. In recent years projector manufacturers have been quite conscious of this factor and measurable improvement has been made. The distortion resulting from azimuth deviation error in a projector is very annoying since it is harsh and raspy and there is very little that a projector user can do to overcome it except to return the offending machine to the manufacturer for proper adjustment.

Much study has been given to the relationship of the slit geometry to the film; the relationship with respect to width is usually referred to as the aperture effect. The slit width for a 35-mm sound projector running at the standard speed of 90 ft. per minute has been established at 0.0013 in. For an equal aperture loss with 16-mm film running at its standard speed of 36 feet per minute, the slit width would be proportional to the film speed; the calculated width would be about 0.0005 in. Only Eastman Kodak and DeVry have supplied 16-mm projectors with a slit as fine as this; all other manufacturers have supplied projectors with coarser slits and correspondingly poorer high-frequency response. The Bell and Howell projectors provide slits of about 0.0007-in. width and are correspondingly better than other machines that use still wider slits—some as wide as 0.001 in. Figure 61* and the following table show the theoretical output of a uniformly illuminated slit that is exactly normal (perpendicular) to the direction of film travel. The data is given in terms of the ratio of the wavelength on the film to the slit width. Figure 61A shows the approximate slit-loss characteristics for a 0.0005-in. slit (with 16-mm film running at the standard speed of 36 ft. per minute), and for a 0.00012-in. slit.

* Data for this curve is taken from the analysis of E. D. Cook which appeared in the JSMPE under the titles ''The Aperture Effect (*JSMPE,* June 1930, p. 650); and ''The Aperture Alignment Effect (*JSMPE,* Nov. 1933, p. 390). The full significance of this fundamental and profound analysis is only now beginning to be appreciated some two decades later. A modern interpretation was presented in 1949 at the Spring Convention of the SMPE in New York by J. A. Maurer; it is to be published later in the Journal. In the light of the recent demands for improved sound quality that are now being made, another paper by Cook should be of interest: ''The Technical Aspects of the High-Fidelity Reproducer'' (*JSMPE,* Oct. 1935, p. 289). Despite the absence of fanfare in its presentation, Cook's work in motion pictures is worthy of close study.

16-mm sound-recording machines use slits appreciably narrower than those used on 16-mm sound projectors. The width of the slit in a Maurer machine, for example, is of the order of 0.00012 in. From the curve shown it can be seen that the loss of a Maurer recording slit is less than 1 db at 6000 cps. For practical purposes this loss is negligible; it is the distortion produced on the film that dictates the use of this very narrow slit.



Theoretical Output of a Uniformly Illuminated Slit Exactly Perpendicular to Direction of Film Travel[a]

Ratio $\frac{\text{linear width of slit}}{\text{wavelength of fundamental}}$	Percent output	Db attenuation
0.0	100	0.0
0.1	94	0.5
0.2	82	1.7
0.3	67	3.5
0.4	48	6.5
0.5	32	10.
0.6	18	15.
0.7	8	22.
0.8	3	31.
0.9	1	40.
1.0	0	∞

Note: Maximum second harmonic due to scanning occurs at ratio 0.32.
Maximum third harmonic due to scanning occurs at ratio 0.5.

[a] For complete opacity on opaque side and complete transmission on transparent side of film.

Fig. 61. Theoretical output of slit in relation to recorded wavelength.

Possible Improvements in Optical System. Although the optical systems of modern sound-recording machines are on the whole fairly well designed, there is still considerable room for improvement. The wider use of coated lenses designed for maximum transmission in the best chromatic range selected as the compromise between best resolving power of the finer grained emulsions and practicable operating conditions, such as lamp wattage, color temperature, and lamp life, would be capable of providing a material increase in the image contrast of the optical system and an important reduction in lens "flare." Improvements in

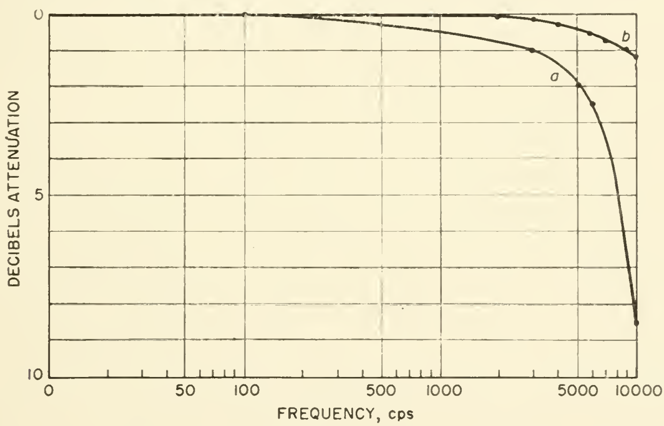


Fig. 61A. Attenuation of one-half mil slit (*a*) and of 1.2 tenths mil slit (*b*). The former is representative of good reproducing practice; the latter of good recording practice.

Calculated Values for 1.2 Tenths Mil Recording Slit (after Cook)

Frequency in kc/s	1	2	3	4	6	8	10
Loss of fundamental in db	—	0.1	0.15	0.3	0.5	0.9	1.2
Zero shift (decimal of fundamental)	—	0.06	0.08	0.12	0.20	0.28	0.32
2nd harmonic (decimal of fundamental)	—	0.04		0.09	0.135	0.18	0.20
3rd harmonic (decimal of fundamental)	—	0.00		0.00	0.01	0.014	0.02

Calculated Losses in db for Various Reproducing Slits (after Cook)

Frequency in kc/s	0.5	1	2	3	4	5	6	7	8	9	10
1 mil slit	0.1	0.3	1.1	2.6	4.9	8.5	14.	31.			
¾ mil slit	—	0.2	0.6	1.5	2.6	4.3	6.5	9.7	14.	23.	
½ mil slit	—	0.1	0.3	0.6	1.1	1.8	2.6	3.7	4.9	6.5	8.5

design such as the directing of unwanted reflections out of the working optical path are also capable of providing worthwhile results. Although present-day systems are not very complex, efforts to reduce the number of surfaces traversed in a system are also capable of providing worthwhile improvements. In general, systems with a small number of optical surfaces are preferable to systems with a larger number. As in the case of objective lenses for cameras, lens coating can provide a very material improvement in the performance of a well-designed multi-element lens system for sound optics just as it does for a Tessar; the improvement in performance with lens coating in a poor design is not great, since lens coating is in no sense a substitute for good design.

In general, all modern 16-mm sound-recording machines use filtered light for film exposure; as has been mentioned previously, Chapter III, an increase in resolving power of the film occurs for exposure at the blue and red ends of the spectrum. Since sound-recording film (as manufactured) is not sensitized for exposure to red light, its sensitivity to light at the blue end of the spectrum is important. For this reason all commercial machines provide exposure for wavelengths shorter than 500 mμ in the blue region (Maurer) or in the near ultraviolet region 400 mμ (RCA). Performance of a recording optical system can be improved materially by correcting the system for only the primary wavelength of interest, and by designing the lens coatings accordingly; this has been recognized by recording equipment manufacturers, and further improvements in design may be expected as a result of their progress along these lines.

Film Loss

At this point something should be said about film losses, since they are a controlling factor in the over-all response-frequency characteristic actually obtained, and therefore should exert a very strong influence on the manner in which the original sound record is equalized and the accuracy of control with which the film-laboratory copying and processing is accomplished. For years it has been the more-or-less vaguely implied objective of designers of sound-recording equipment to provide equipment to have a response-frequency characteristic that is "flat to the print." This means merely that all losses and corrections in the recording and reproducing systems must be anticipated up to and including the making of the release print, and, in addition, to correct for such projection conditions as the level difference between the original event and

the reproduction level during projection. This objective does not anticipate the losses found in the reproducing of the film by the sound projector; at present, such losses are presumed to be anticipated by the designer of the sound projector when he designs that machine.

Film loss in a projector may be measured by comparing the response of the projector when constant modulated light from a galvanometer strikes the reproducer photocell with its response when a constant-amplitude film is scanned by the projector scanning beam. The difference between the two characteristics is usually called film loss. Film loss is usually difficult to evaluate for comparison purposes because differences in processing that are dictated by different recording methods and by the variety of processing methods actually used, result in different performance in terms of the character and amount of the distortion produced and in terms of the amount of noise produced.

Designers of sound projectors have had this situation in mind when designing their machines despite the fact that there never has been specific agreement among designers of sound-recording equipment and of sound projectors as to just where one stops and where the other begins. The practice as it now exists is followed because of the not-too-applicable precedent set in the design of 35-mm recording and reproducing equipment. Fortunately for the 35-mm industry a "standard" slit width of 0.0013 in. was selected by the Research Council of the Academy of Motion Picture Arts and Sciences for 35-mm reproducing equipment, and commercial equipment manufactured meets this "standard." This width represented the best compromise between cost and response characteristics. Designers of 16-mm projectors have not been fortunate enough to have a "standard" slit width for their machines; in addition, 16-mm film losses are much greater in magnitude than for 35-mm film. 16-mm film losses are much more variable in practice because a relatively much higher degree of control is required for 16-mm than for 35-mm if the same order of variation in the over-all result is to be expected. This is primarily a result of the fact that the film speed of 16-mm film is only 40% that of 35-mm; the recording is crowded linearly into only 40% of the space along the film. For such reasons, accuracy and extreme attention to detail must be the guide to successful 16-mm sound quality.

To accomplish the objective of designing a sound projector to be "flat to the print," most early 16-mm sound projectors, being deficient in high-frequency response because of a coarse slit in the projector sound-scanning beam, used a "peaked" (equalized) amplifier to

compensate for the scanning deficiencies of the optics. These early machines used slits that were 0.001 in. and larger in width; about 3000 cps was the highest practicable frequency for peaking as it is not feasible to peak at any frequency higher than approximately 50% of cutoff frequency.* Since peaking is merely a form of equalizing and can only be accomplished at the cost of an increase in noise and in distortion, it was no wonder that the earlier sound projectors were quite noisy when compared with present-day machines of better manufacture, which do not require peaking to provide satisfactory response to high frequencies.

When 16-mm prints made by optical reduction from 35-mm originals were first run in the early 16-mm projectors, the film losses found in the 16-mm print were very large compared with the losses found in a 35-mm print. Since the same 35-mm sound negative was used to provide the 16-mm prints as was used for the 35-mm prints, the 16-mm prints proved very deficient in high frequencies by comparison. Projector designers

TABLE XVI
Slit Width *vs.* Cutoff Frequency

Slit width, in.	Cutoff frequency, cps	Slit width, in.	Cutoff frequency, cps
0.0012	6,000	0.00050	14,400
0.0010	7,200	0.00040	18,000
0.00075	9,600	0.00014	51,400

thus found it necessary to peak the amplifiers still more to compensate for the film losses that they encountered.

A number of projectors being manufactured today still cling to the inadequate 0.001-in. slit which is entirely too wide for satisfactory projection. The loss of a 0.001-in. slit is some 14 db at 6000 cps; should this large loss be added to the film loss usually encountered in the making of a 16-mm reduction print from a good, yet unequalized 35-mm original sound negative, the total loss would be about 30 to 35 db. The large film loss of 16 to 21 db is found in run-of-the-mill reduction prints made even today in many commercial film laboratories. As the signal-to-noise ratio of even excellent 16-mm projectors under practical operating conditions cannot be expected to be greater than 25 db, it is obvious that such

* Cutoff frequency is that frequency for which the width of the slit is equal to the length along the film for one wavelength. Cutoff frequency may be determined by dividing 7.2 in. per second (the speed of 16-mm film) by the slit width measured in inches; the result is the cutoff frequency in cycles per second. Some cutoffs of interest are found in Table XVI.

prints run on such projectors cannot possibly produce any useful signal in the loudspeaker of the sound projector at 6000 cps. Incidentally, equally poorly controlled 16-mm prints made from a good, yet unequalized, 16-mm sound negative may be expected to show similar losses.

A good 16-mm release print made directly from a good 16-mm sound negative in accordance with good current commercial practice shows a loss of 8 or 9 db at 6000 cps. The scanning loss of a projector with a 0.0005-in. slit (such as in some of the Eastman Kodak projectors) is only some 3.5 db. As the total loss in this case would only be about 12 db, it is possible to produce some useful signal at 6000 cps by such operation. With the large processing losses that are common, however, it is almost impossible to deliver a useful 6000-cps signal, on any projector regardless of its slit loss and other characteristics if poor processing of sound film is used.

The better present-day sound projectors (such as the Bell and Howell) use a slit of 0.0007 in.; this slit width shows a scanning loss of 7 to 8 db at 6000 cps. The "loss to the release print" of a good 16-mm print printed directly from a good 16-mm sound negative in accordance with the best commercial practices is of similar order. It is apparent that as quality demands are pushed farther upward, projection equipment, recording equipment, and processing will have to be improved. A conventional post-war Bell and Howell Model 179 sound projector together with such excellent prints from a suitable equalized 16-mm sound negative would prove a revelation to the average user of 16-mm equipment.

It should be quite apparent from the foregoing that the quality which appears on a release print can be predicted fairly accurately if the conditions under which the films are to be recorded, processed, and projected are known and taken into account. If the conditions are not known, it is quite certain that the results will be poor and definitely inferior to that which was expected. It has been truly said that the "cards are always stacked against the haphazard film handler."

As there has been no standardization of 16-mm projector slit widths or, for that matter, of any 16-mm response-frequency characteristic* for

* The Subcommittee on 16-Mm Sound Reproduction of the SMPE has been attempting to establish empirically a reproducing system electrical characteristic in the same general manner as that used for establishing the "Standard Electrical Characteristics for Two-Way Reproducing Systems in Theatres" recommended by the Research Council of the Academy of Motion Picture Arts and Sciences on October 10, 1938. To eliminate the hopeless variable introduced by the very wide disparity in

(*Footnote continued on page 256*)

a projector, it is almost impossible to anticipate the wide variety of projector response-frequency characteristics that are in commercial use. A good commercial procedure is to select a particular make and model projector as a reference and to equalize all recordings so that they are run with the projector controls of the reference machine in the ''normal'' position. The selection of the reference projector must be made with great care; its characteristics should remain constant from day-to-day and month-to-month; its specifications should deviate but the least practicable from those of the American War Standard Z52.1-1944 ''Projection Equipment, Sound Motion Picture, 16-Mm Class 1.'' Should it be possible to specify the projectors to be used for the projection of the film to be produced, all should be preferably of the some make and model as the reference machine.

For the protection of the purchaser and for the mutual benefit of all concerned, it seems that standardization of the slit-loss response-frequency characteristic and standardization of either the system response-frequency characteristic up to the amplifier output or standardization of the over-all response-frequency characteristic of 16-mm sound projectors is sorely needed. Effective standardization has existed for 35-mm projection for more than a decade and the time for similar standardization in 16-mm is long overdue.

To compensate for film loss, it is first necessary to know the actual film loss. Therefore, a decision must be made as to just how films are to be processed and copied, and no deviation can be permitted from the procedure so established. It is possible to keep this loss to as low as 8 db per step if great care is exercised; a loss of 20 db or even more can occur in the single step from the original sound negative to the release print under poor laboratory conditions; unfortunately, such losses are not rare.

Some recent Maurer 16-mm recording equipment provides equalization for film losses in three steps of 3 db, 6 db, and 9 db occurring at about 5500 cps. Whether this equalizing or, for that matter, any other equalizing is satisfactory will depend upon the film losses to be encountered and the characteristics of the sound projectors to be used. The outlook for good sound quality would seem hopeful for the better 16-mm sound pro-

---

performance of commercial loudspeakers supplied with 16-Mm projectors, the Subcommittee has chosen to make its test with two-way reproducing systems such as are used in theatres. Although there is some difficulty in establishing the correlations of pre-war two-way loudspeaker systems with the larger number of post-war two-way systems of somewhat different performance, the progress made is very encouraging.

jectors with the very best commercial film processing control; it would seem hopeless for the poorest of present-day projectors and uncontrolled run-of-the-mill processing.

Manufacturers now build their latest equipment capable of recording a direct positive as well as a negative sound track, and of recording variable density as well as variable area. In the case of the Maurer machine these changes are made by merely turning a control knob or by moving a lever. By recording a direct positive it is possible to eliminate the losses attendant to the printing of an extra intermediate film. The arrangement of the optical system is quite similar to that already shown in Figure 60. The significant differences are: (*1*) the noiseless recording bias is reversed so that the maximum exposure width is provided when no modulation is present and (*2*) an inverted mask wider than the negative mask is used; the maximum width is about 0.080 in. rather than the negative width of 0.060 in. Modulation occurs, however, only to a maximum of 0.060 in. in accordance with current standards.

At present there are two common forms of variable-area sound track in commercial use, bilateral variable area, as used in Maurer equipment and obtained by applying the noiseless recording bias current to the mirror galvanometer armature, and duplex variable area, as used in earlier RCA equipment and obtained by applying the noiseless recording bias current to a pair of shutters cooperating with the galvanometer in limiting the width of the light beam transmitted by the recording machine optical system to the film. Recent RCA recorders are returning to the biased galvanometer arrangement.

Up to the present there has been no serious attempt to use push-pull either on 16-mm film or on 35-mm film for release purposes. Although 16-mm push-pull sound tracks are not used commercially despite the fact that 35-mm push-pull sound tracks have been in use for about a decade in Hollywood for making original sound tracks that are later used for re-recording in Hollywood studios, it cannot be safely said that 16-mm direct positive push-pull recording will never be made. The demands for improved quality in 16-mm sound are ever growing and whether 16-mm direct positive push-pull sound tracks come into wide use may depend upon how forcibly those demands are made.

A push-pull sound track is a sound track in which there is a septum dividing two parts that are equal in width; these parts record the signal in opposite phase to one another. As in amplifier classifications, there are class B sound tracks and Class A-B sound tracks. In class B, compression waves are recorded upon one half, and rare-

faction waves are recorded upon the other half; the signal when applied to a push-pull photocell by means of a divided light beam acts in a manner comparable with that of the output of a pair of electron tubes operating under class B conditions. In a

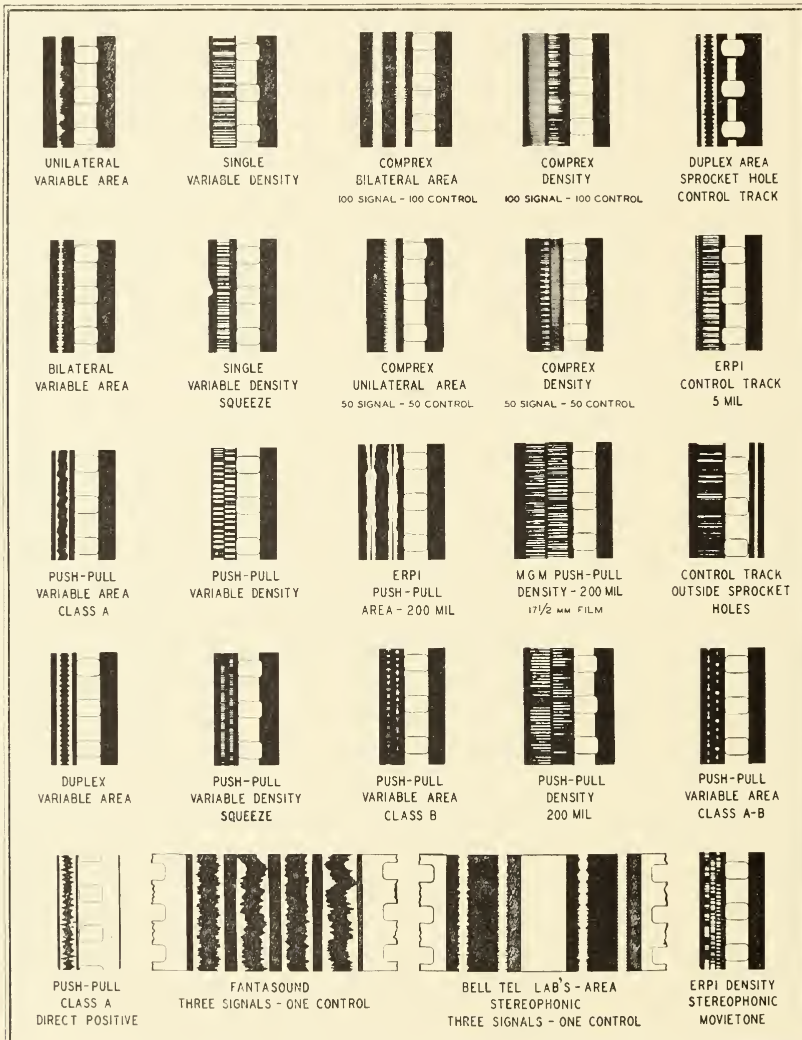


Fig. 62. Sound track types and their accepted names.

class A-B sound track, the light transmitted through one part of the track increases, while the light through the other part decreases; the action is quite similar to that of a class A-B amplifier. A noise-reduction (bias) amplifier is used to provide unidirec-

tional bias current for noise-reduction recording with the class A-B sound track; no bias equipment is required with the class B equipment. Either type may be variable area or variable density; variable density class B has not been used however. Figure 62 illustrates a number of types of sound tracks used commercially and gives their accepted names.

Price vs. Performance in Recording Equipment

The manufacture of 16-mm sound-recording equipment has not been a lucrative business in the past; the quality required for successful competition has been high and the market small. In a sense, the manufacture of such equipment has been a proposition more for a model shop than for a production line, and the prices charged and the sales policies have reflected it. New companies have not hurried to get into the business; rather, those already in it have to a considerable degree been figuring ways and means of staying in it without sacrificing equipment quality.

Small-quantity production of unrelated material results in such high unit costs that an item such as a recording machine may be priced out of the market. To avoid this dilemma to an extent, companies have been manufacturing sound-recording equipment with as many interchangeable parts as possible. As an example, to obtain low flutter, the recording drum of one sound-recording machine is of such large diameter that the eccentricity-introduced flutter rate is only 1 3/4 per second. This and numerous other parts are then used interchangeably in the film phonograph and in the optical one-to-one sound printer also manufactured. Such use of the same parts in several machines increases materially the size of the "production run" possible for individual parts and reduces the cost per part.

The quality of modern sound-recording machines, film phonographs, and sound printers of such manufacture is high by competitive standards. When this equipment is used under the best laboratory-controlled conditions, reproduction of films upon a film phonograph with a good amplifier and loud-speaker show distortion of almost similar low order to that found in pre-war, well-controlled Hollywood studio recordings with one exception—there is a somewhat higher noise level. The theoretical limitation for such reproduction at present appears to be in the film.

The slit image provided in one recording machine (as set for variable-area recording) is about 0.00012 in.; stray light in the optical system has been materially reduced by decreasing the number of optical surfaces that a ray must pass, and by utilizing anti-reflection coatings. All lenses

are coated to provide maximum transmission in the violet (400 mμ) end of the spectrum. The lens system is also corrected for the red end of the spectrum so that the machines may be used for exposing sound track on Kodachrome and other integral tri-packs such as AnscoColor. The same general optical design is used for the film phonograph and for the sound printer as these machines may also be called upon to run integral tri-pack films as well as black-and-white films.

Recording machines are focussed at 15,000 cps in production; every machine shipped has made a reasonably clear-cut record at this frequency. The galvanometer used in the machine resonates at 12,000 cps; the resonance amplitude is about 7 decibels. A small dip occurs in the response-frequency characteristic at 4500 cps. This is corrected by a resistance-capacitance equalizer. With good commercial processing, a print on Eastman 5302 film is about 15 1/2 decibels down at 10,000 cps when made from a "flat" negative recorded upon Eastman 5372 film. This performance is now as good at 10,000 cps as was the performance of 1939 at 6000 cps. The recording machine can provide either negative sound track or direct positive sound track at will. Depressing and rotating a knob changes the type of recording from variable-area to variable-density by removing one of a crossed pair of cylindrical lenses from the optical train where they act as an objective.

A new film phonograph using as many parts as possible in common with the film-recording machine has a reproducing slit width of about 0.0003 in. The slit loss of this machine is quite small at 10,000 cps; the photocell and its coupling circuit account for a considerable portion of the over-all loss. As the intermodulation distortion can be made quite low on the film, it has been practicable in a production machine used for test to equalize the associated preamplifier so that the over-all response of the film phonograph is "flat" to 10,000 cps. The over-all quality obtained with a print compares quite favorably with that obtained using a 35-mm Hollywood product in a well-maintained neighborhood entertainment theater. Widespread use of film of such quality is a possibility for the foreseeable future when projection of such films on good projectors under suitable acoustical environment will enable the 16-mm sound film to be an even bigger and better tool than it is today.

The Recording Amplifier

Functional Components

Although the physical forms and arrangements for recording amplifiers vary widely, modern equipment is characterized not so much by

outward appearances as by measurable performance characteristics such as the excellence of signal-to-noise ratio, low distortion, and a wide frequency range that is limited only by the band-pass filters (Fig. 32) intentionally introduced to limit the transmission to the desired frequency range. Thus it is now common practice to make all amplifiers used in modern 16-mm recording equipment with good fidelity to 15,000 cps; in fact, manufacturers recognize that the wider the frequency range of the recording system in comparison with the frequency ranges actually employed in commercial recording, the more predictable and reliable will be the final result. Thus, although it may be rare to employ commercially in a film recording any range wider than range F (110 to 5300 cps), the basic equipment supplied by the major manufacturers has good response in the range from 50 to 15,000 cps and low intermodulation distortion throughout. As demands for range increases are made, they can be met by providing new band-pass filters rather than completely new equipment.

The cascade amplifier, although no longer composed of filament-type triode tubes, invariably has heater-cathode type electron tubes in all audio circuits between the microphone and the recording machine. For convenience in audio mixing and in using equalizers at the most suitable audio levels, amplifiers are now made in three portions:

(*1*) A preamplifier—used to increase the level from the microphone about 25 to 50 db before the signal is applied to the attenuator (''mixer pot'') of the mixer panel. If used, the output of a re-recording film phonograph may be connected to a second attenuator of the mixer panel to effect mixing with the microphone output.

(*2*) An intermediate level amplifier—sometimes called a main amplifier—used to increase the level from the mixer panel output some 40 to 70 db more. At this higher level the signal passes through the equalizers to the output amplifier to the noiseless recording (''bias'') amplifier and to the compressor.

(*3*) An output amplifier—the output is connected to the light modulator of the sound-recording machine.

Electron Tubes. Rugged tubes of low microphonic sensitivity (such as the 1603, 1620, and 5879 types) are usually found in all preamplifier and low-level stages such as those immediately following the microphone and the re-recording film phonograph. The importance of well-selected electron tubes is hard to overemphasize, since the loss of a few minutes of recording time will more than offset the cost of even the most expensive electron tube used in the equipment. Over-all performance depends in great measure upon the performance of the electron tubes used.

The performance of an electron tube in a circuit arrangement depends upon the permissible variation of the tube for which the circuit

is designed and the permissible variations of the circuit arrangement constants. JAN (Joint Army-Navy) specifications prescribe specific limits for electron tubes, and no tube outside the limits is permitted to carry the JAN marking. Unfortunately, published characteristics of commercial electron tubes represent ''average'' characteristics, and, although certain tolerances are expressed or implied, such tolerances are ''nominal'' and do not constitute a representation by the manufacturer that all tubes sold are within the published tolerances. Since an efficient design requires that both tube variations and circuit variations be known and taken into account, the performance of an efficient design is likely to be ''out of limits'' if random tubes are used because there is no certainty that a randomly selected tube will be within prescribed tube variations. Where tolerances are too wide, the performance of the electronic device is relatively poor and/or it will have too many components, making it too costly for the performance obtained.

During World War II, it was American military practice to require that the performance of any electronic device be within specification limits with any electron tube of correct JAN type chosen at random. Unfortunately this excellent practice does not carry over into civilian equipment; it is necessary to inquire of the manufacturer of sound-recording equipment whether the claimed performance is obtained with run-of-the-mill commercial tubes, whether special tubes are required, or whether special selection of commercial or special tubes is required. In the latter case inquiry should be made as to the selection criteria and the ''go'' and ''no-go'' limits for each type involved. This is valuable practical information needed to obtain the most satisfactory operation of the equipment in service.

If the product of one particular tube manufacturer (*e.g.*, Sylvania) would be better than that of another manufacturer (*e.g.*, RCA) for a particular type (*e.g.*, the 6P5G which is used occasionally as a selected preamplifier tube), this should be specified by the manufacturer of the recording equipment. The manufacturer should be expected to keep satisfactory replacements in stock for delivery to the customer. It is well to remember that in electron tube manufacture, just as in other competitive manufacture, the suitability of a particular type for a specific specialized purpose may vary over wide limits from one manufacturer to another.

To reduce to a reasonable minimum the wide range of performance variability due to electron tube variations, recording equipment manu-

facturers often stock replacement tubes for their apparatus. The performance claimed for the apparatus can be obtained not only with the tubes supplied as original equipment, but also with those supplied as manufacturer-furnished replacements. Selected tubes carry a higher price than unselected tubes; the price difference customarily reflects the additional cost of selection.

In some instances equipment manufacturers may offer special electron tubes for sale that provide appreciably better performance compared with the run-of-the-mill commercial product. Typical examples are the Western Electric 348A and 350B; these are quite superior to the commercial 6J7 and the commercial 6L6—their respective equivalents. Oftentimes as in the case of Western Electric equipment such special tubes are subject to sale restrictions and are not available for 16-mm sound-on-film recording purposes except as part of a piece of equipment leased by Western Electric or RCA on a royalty basis.

Where long life is important as in industrial tubes, RCA markets special tubes known as the ''red-top'' types. The 5691 (equivalent to the 6SL7GT) and the 5692 (equivalent to the 6SN7GT) are rugged and can withstand shocks of 500 g for short periods, and 2.5 g for hundreds of hours continuously; these tubes require 0.6 ampere for the heater. The 5693 (equivalent to the 6SJ7) is a long-life rugged tube using the same heater current as its commercial equivalent; apparently its outstanding characteristic is low gas current, since under prescribed conditions it is capable of operating with as much as 40 megohms in the circuit of grid #1.

Should a recording equipment manufacturer supply selected tubes for his equipment, the selection criteria are not at all mysterious. Selection in usually made for:

1. Tube noises—such as hiss, hum, and random ''pop'' noises.
2. Microphonic sensitivity—the ''bong'' or howl sound heard when a susceptible tube is mechanically tapped.
3. Special electrical tests—these are dictated by the specific need—they may be such tests as uniformity of μ (amplification factor), G_m (mutual conductance), Z_p (plate impedance), ''drift,'' grid circuit gas current, etc.

The Tube Department, RCA Victor Division, Harrison, N. J. advises as follows: ''Types such as the 1603 and 1620 which are sold as non-microphonic types are specially tested for such items as hum, noise, and microphonics. Other items such as g_m, r_p, mu, and heater-cathode voltage rating are held to the same limits as the prototypes.

''The special tests include hum measured with a low-frequency amplifier, and hiss, noise, microphonics, and pops all measured with a wide-band amplifier. Limits on each of these items have been established to correlate as well as practical with the results obtained in commercial high-gain, high-quality audio amplifiers. In general, heater-cathode insulation tends to improve with age.

"So far as pops are concerned, the test permits with a 30 to 10,000 cycle-per-second amplifier two pops per minute. If more pops than this show up, the test is continued for a second minute and the tube rejected if the second test repeats the first. . . . So far as the life of the 1603 and 1620 versus the prototypes is concerned, I would expect little inherent difference between the two classes of tubes in this respect. . . . The demand . . . for tubes of this kind is relatively small and does not justify very much expansion in the number of tubes (types) at the present time."

Responsible manufacturers are prepared to supply such data to customers who are interested.

To obtain outstanding performance of sound-recording equipment it is necessary for the recording engineer to have available tube-testing equipment and facilities, and to know how to use them. Tube "hiss" is the noise that should be predominant in a monitor loudspeaker when the gain of the system is advanced, say, 30 or 40 db above normal operating gain. To keep the hiss to a minimum, tubes should be selected for the low-level stages, and more particularly for the first stage. Practically speaking, tube hiss is a function of two factors primarily: (*1*) the gain of the tube measured as amplification factor (μ) or as mutual conductance (G_m) and (*2*) the gas current in the control grid circuit of the tube. All other factors being equal, the best tube for minimum hiss is the tube with the highest gain and with the least gas. Gain can be measured on test sets such as those made by General Radio and by Weston; gas can be measured by setting up an equivalent circuit (a circuit to simulate the circuit actually used, using the same kinds and values of condensers, resistors, and coils) and connecting a microammeter (range 0–5 microamperes) in series in the grid return circuit to the cathode of the tube. If, say, a dozen 1603 tubes are checked in this manner, individual differences will be quite significant, and the "best" tube of the lot can be selected. The tube to be placed in the socket of the first amplifier stage of the equipment is the tube that shows the least sensitivity to microphonics and is the best under the above gas test.

Among commercial-output electron tubes, the 6V6GT/G is one of the most satisfactory. After being turned on, it "settles down" in a matter of a minute or so and stays quieter for a longer time than most other similar types. Even in this excellent type, however, there is a wide variation with respect to random "pops" from tube to tube of a single manufacturer and from one manufacturer's product to that of another. Some of these "pops" occur as a result of expansion of internal parts due to heating. Commercial 6L6 tubes (both metal and glass) have had a reputation for variability and high noise level, the metal type seeming to be the worse offender. Should an output tube of such power be re-

quired, either the directly interchangeable Western Electric 350B, the commercial 1622, or the mechanically different 807 are definitely preferred. Fortunately there are few if any points in a sound-film recording system where the maximum power delivered by a pair of such tubes in push-pull is ever required.

In the case of electron tubes that operate in high impedance circuits, glass tubes are usually more satisfactory than their metal counterparts despite higher interelectrode capacitances. This seems especially true in circuits in which the impedance exceeds about 1/2 megohm. Although metal tubes may provide equal performance with regard to tube noise when new, they usually become more noisy more rapidly and show appreciably higher noise levels at the end of as little as 200 hours of operation. A 6H6G, for example, would be a better choice than a 6H6 as a diode rectifier in a compressor, noiseless recording, or other signal-controlled circuits.

Electron tubes of high mutual conductance designed for television purposes such as the 6AC7 are not ordinarily applicable to sound-film recording equipment. Despite the advantage of high mutual conductance, their microphonic sensitivity is relatively so high that they represent a poor design choice under usual circumstances of application.

In preamplifiers, where signal level is low and leakage and noise must be kept to a minimum, electron tubes with the grid connection at a grid cap are preferable to single-ended tubes where the grid connection appears at the base. If a glass tube is used, not only is the physical separation of the grid from other tube elements great, but also the path external to the tube is of high resistance. Thus, a 6J7 would be a better selection than a 6SJ7; a 6J7G would be still better.

Special tubes are available in both metal and glass that are designed for low sensitivity to microphonics (noise resulting from the mechanical movement of the tube elements caused by vibration) and for low internal noise such as hiss, hum, and random "pops." The most common are the 1603 (glass) and the 1620 (metal); these are electrically equivalent to the 6C6 (glass) and the 6J7 (metal), respectively. The 6J7, 6J7G, and the 1620 are octal-base tubes; the 1603, like the 6C6, has a six-pin base. All five have similar electrical characteristics except for noise and for differences in interelectrode capacitances. In designing a preamplifier to use one of these five tubes in the first stage, the choice would be the 1603. Oftentimes, two-stage preamplifiers make use of a 1603 in the first stage and a 1620 in the second stage; because the 1603 type tube

is not available in an octal base, users are forced to keep unnecessarily large stocks of spare tubes on hand for replacements. It would be a great advantage to the user if the 1603 type could be made available in the octal base, since it would then be possible to design equipment with but a single type of electron tube socket for amplifier tubes.

All of these pre-amplifier tubes are designed for 6.3 v., 0.3-ampere heater operation; to make matters still more complicated for the user, most of the 12 v., 0.15-ampere nonmicrophonic tubes that are available have neither the octal nor the six-pin base but use instead a third type of tube base, the Loktal. For most purposes the use of three types of bases in this manner is most wasteful and tube manufacturers should be urged to "clean up" this unhealthy situation through the Radio Manufacturers' Association or other industry-standardizing body.

Unfortunately, there are too few special low-noise tubes available. The only other low-level tube worthy of mention is the 1612 (metal); this is electrically equivalent to the 6L7 (metal). Generally speaking, the variation from one tube to another is smaller for special tubes than it is for their commercial equivalents. Despite this, appreciable variations will still be found in the performance of special tubes when they are tested for critical applications such as in the first stage of a microphone preamplifier. Important variations are found not only in electrical characteristics, such as mutual conductance, etc., but also in noise output such as microphonic rattles, howls, random pops, hiss, hum, etc. The average of a group of special tubes such as the 1620, for example, is considerably better than the average for a group of commercial equivalents such as the 6J7. Even with special tubes it is good practice to have several pre-tested spares on hand so that it is possible to select the outstanding tube from the group for the most critical application. The best test for microphonics is the testing of a special tube in the particular socket of the particular amplifier (or prototype) in which it is to function. The absence of special tubes in a preamplifier can be considered a mark of inferior design. Any preamplifier that does not use nonmicrophonic tube types should be looked upon with suspicion regardless of the excellence of the design of the shock mounts for its tubes. The best nonmicrophonic 6.3 v. tube now available for use in the first stage of the microphone preamplifier or in the preamplifier associated with a film phonograph or other low-level input is the 1603. The absence of a 1603 tube in the preamplifier may be considered an unnecessary handicap in the attainment of good noise-free performance of the recording equipment that fails to use it.

If a recording system is to provide the highest practicable signal-to-noise ratio, it can not be accomplished with line frequency alternating current applied to the heaters of the low-level tubes even if special tubes are used. Appreciable hum due to emission and to magnetic induction as well as leakage occurs between cathode and heater of even the best special tubes; accordingly, all low-level amplifiers should be heated from a unidirectional current source such as a storage battery or from a good low-voltage rectifier and associated filter. The performance of an alternating-current energized rectifier-filter type of low-voltage power supply that is properly designed is every bit as satisfactory as a storage battery and is far less of an operating nuisance. All modern 16-mm sound recording equipment uses unidirectional heater-current supply energized from the mains at least for its low-level amplifiers; still better design uses unidirectional heater-current supply in all equipment between the microphone and the sound recorder. The performance of preamplifiers in which the signal level is minus 20 db* or less can be improved materially if the noise-*vs.*-life characteristics of practical tubes are understood, and suitable design precautions taken. Almost invariably the first tube in such an amplifier should be a 1603 connected as a triode; almost invariably too its heater voltage should be about 5.3 v. and the voltage at its plate (not the supply voltage) about 40 to 50 v. The tube should have the customary shield can; if a-c. fields are nearby, a thin permalloy shield should be wound inside the shield can. Heater current should be unidirectional; either a rectified and well-filtered supply energized from the a.-c. mains or a storage battery will suffice. Operating the first tube under these conditions will result in materially lowered tube "rush" noise and tube hum, not only when the tube is first placed in service, but also with increasing tube age. A further advantage is that the 1603 has its grid cap quite distant from its heater terminals; under unfavorable humidity conditions, the glass envelope of the tube still provides a long path of high resistance and of low capacitance between the control grid and other terminals.

Amplifiers using alternating current for tube heaters can often be improved by operating the cathodes at a negative potential with respect to their heaters; this reduces the effect of hum due to emission. If the operating level of the input stage is low and but a small space current is required, the heater voltage may be dropped from its rated voltage of 6.3 to about 5.3. Generally speaking, biasing of the heaters with re-

* With respect to 1 milliwatt in 600 ohms (reference level).

spect to the cathodes may be accomplished with a tap from the plate supply bleeder; a positive voltage of about 50% greater than the peak voltage of the a.-c. heater voltage is usually satisfactory. In such an arrangement, the cathodes are at the most negative potential; the heaters are then positive with respect to the heaters by the amount of voltage at the bleeder tap.

Manufacturers have been aware of the potential increase in demand for electron tubes of long life and of consistent performance. Such tubes have been made available on the open market only recently despite the fact that electron tubes with 50,000-hours-life performance have been common for years among the Western Electric tubes manufactured for American Telephone and Telegraph Co. telephone repeater service. RCA has available a "red tube" series previously mentioned that is intended to be more rugged than the usual commercial tube of 1000-hour rated life; the rated life of this new series is 10,000 hours. Sylvania has recently been marketing tubes of the 1603 type with a 12-v., 150-mil heater and with an Loktal-type base. There is real need for such new tubes due to the increase in the quantity of electronic control equipment used in industry; ordinarily, the failure of a tube in a continuous manufacturing process is a serious matter that results in losses far greater than the cost of the best tube in the market.

Amplifier Component Parts. World War II taught manufacturers and their engineers a great deal about the manufacture of amplifiers and their component parts. Prior to the war, equipment was expected to perform consistently only indoors where the temperature and humidity variations were quite small. The war in the Pacific made it necessary to manufacture equipment that would perform in both the Arctic regions as well as in the tropics, since aircraft were required to fly missions in both areas and to transfer their operations from one area to another as the tactics required. Altitudes of 40,000 feet became common; equipment was required to function in any climatic conditions and at any altitude. There were many equipment failures when the first equipment manufactured was placed in service.

Transformers, coils, and condensers had to be hermetically sealed. Many materials formerly used for insulation of coils such as paper and cotton had to be eliminated in favor of non-nutrient materials such as spun glass, acetate, Vinylite, and similar synthetic sheetings and tubings.

More recently, about 900 pounds of electronic equipment was installed in the warhead of a V-2 rocket that was fired at White Sands, New Mexico, where the equipment

functioned quite satisfactorily under extraordinary conditions of temperature, pressure, and acceleration.

The war also brought about the development of rugged glass-envelope vacuum tubes capable of withstanding 20,000 g linear acceleration and 5000 g radial acceleration*; these were used in tremendous quantities in the manufacture of the proximity fuze—a shell fuze that contained a miniature radio transmitter and receiver for controlling the detonation of the shell. Many of these war-learned lessons have been carried over into peace-time manufacture.

For most ordinary purposes, it is considered desirable but not necessary for sound-film recording equipment to meet the rigid performance requirements set for military amplifiers and the like. The latter was excellent in performance consistency; it was, however, quite costly and quite bulky. Engineers all agree that it is "the right way to build equipment," but their sales engineers feel that a competitive market is not prepared to pay the high prices that its construction involves. Unfortunately, too, the quantity in which 16-mm sound-film recording equipment is built is minute when compared with the quantity of military equipment built during the war. On a comparative basis, accordingly, recording equipment will be less reliable and less consistent as well as more costly per pound, because of the absence of the economies resulting from mass production.

Noise may originate in a number of sources in component parts. The first source to be suspected is a defective tube; hum may also be present because of insufficient filtering of the high- or low-voltage supply, but it may also be due to magnetic induction caused by stray magnetic fields "sprayed" by transformers, reactors, motors, and the like. In good equipment, power transformers and reactors are designed to operate at low flux densities and with special features of magnetic circuit design to reduce stray flux to a minimum. Special magnetic shields made of nickel-iron alloys such as permalloy, Allegheny metal, Mu metal, Nu metal, Hipernik, etc., are placed around audio transformers and other inductive circuit components such as reactors and equalizer coils to minimize the voltages induced by stray fields that may occur. Generally speaking, the stray fields produced by alternating current motors (such as the motor on the sound-recording machine) are the worst offenders in "spraying" stray flux about; reactors and power transformers come

* The term "g," when used in connection with acceleration, refers to the acceleration of gravity: *viz.*, 32.2 ft. per second per second (ft./sec.^{2}).

next, particularly if they do not have both the specialized magnetic circuit design such as is found in modern Western Electric, Langevin, and Altec-Lansing units that also operate at low flux densities.

Hum induction in heater-cathode circuits of amplifiers is best controlled by eliminating the source of the disturbance; unidirectional heater supply is the only complete answer—as has been pointed out.

Special mention should be made of the resistors used in low-level circuits such as in preamplifiers. There is a wide range of variation of noise among the presumably similar products of different manufacturers; the high price of a composition ("firecracker") resistor is not an assurance of satisfactory performance. Usually, composition resistors* used in plate circuits and in grid circuits which are of the 1/2- and 1-watt rating are quite consistent in performance in the Allen-Bradley make. For consistent performance in low-level circuits over long periods of time, there is no substitute for wire-wound resistors such as the IRC WW-4 type.

Coupling condensers in preamplifiers and other low-level amplifiers should always be of the best moulded mica types**; the performance demanded of a preamplifier cannot possibly justify the use of poorly sealed conventional tubular paper condensers for such operation. By-pass paper condensers are best and most costly in the hermetically sealed types†, as used in military equipment; just how far a designer goes in this regard is controlled by the market price of the finished equipment and by the service expected from it. For permanently installed rack-type equipment of long life expectancy, they are quite necessary; for portable equipment where performance must be sacrificed somewhat to achieve light weight, lighter types may be used. Ordinarily, equipment designed for long life will be appreciably heavier than equipment designed for shorter life due to the extra weight of the hermetic seals and the special cans or cases used, in addition to the more generous design. Generally speaking equipment of reputable manufacture is well designed and can be relied upon to have good component parts. Under ordinary operating conditions, a thorough check of all equipment (condensers in particular) several times each year is sufficient to detect defective components before interruption in service or actual breakdown occurs. In general, electron tubes are not as consistent with regard to noise as are other

* American War Standards C75.7. and C75.17.

** American War Standard C75.3.

† American War Standard C75.16.

components; regular checking—especially for noise— is required at relatively frequent intervals. This is especially true of tubes of the commercial variety.

Routine Amplifier Checking. Since modern equipment is designed for good transmission to 15,000 cps, there is no need for any equalizer to correct for transmission deficiencies of the amplifier. Should the range-limiting filters of a recording equipment be temporarily disconnected, the frequency range of the equipment would be "wide open." This condition is very useful when checking a system for noise, since the human ear becomes increasingly critical of noise and distortion as the frequency range is increased.

In most cases the disconnecting of the range-limiting filters of a recording equipment will more than double the frequency range of the sound heard on the monitor loudspeaker. Since the "rush" noise heard in the monitor speaker is appreciable when the frequency range is "wide open," day-to-day variations in channel noise can be plainly heard or otherwise observed. One simple check that can be made quickly as a routine matter is to replace the microphone of the system temporarily by a shielded wire-wound resistor of equivalent resistance, increasing the gain setting of the equipment about 20 to 30 db above customary operating gain setting during the listening interval. This test will point out changes in noise, and with a little experience, serious noises can be distinguished by ear from "tube rush." Electrically noisy and microphonic tubes will usually account for most of the maintenance time in equipment of good commercial manufacture.

When equipment is in everyday use, it is customary to make a "channel check*" before the start of each day's work; a more thorough check is customarily made at less frequent intervals, such as once each week. In a channel check, it is customary to run a rapid response-frequency characteristic test using an audio frequency oscillator source such as a Hewlett-Packard Type 200 Oscillator. The ordinary procedure is to make a number of measurements throughout the frequency range at se-

* Channel check is an ambiguous yet useful term that customarily refers to a response-frequency characteristic and other checks of the complete channel. It would usually involve a test with an audio oscillator in which the test signal is fed into the input of a preamplifier or other convenient low-level point in the recording channel, and the electrical output of the channel observed on a volume indicator, cathode ray oscillograph, or other convenient instrument. The test usually consists of a single quickly-run response-frequency characteristic test for the purpose of locating noticeable differences between the test being made and the previous tests.

lected frequencies, measuring the various outputs throughout the system. In most cases defective components will cause a noticeable (although not serious) change in response-frequency characteristic before actual breakdown or other serious interruption in service occurs. With suitable engineering personnel available, it is possible to check equipment still more thoroughly and to make routine noise and distortion measurements, as well as to make cross-modulation and square-wave tests and to correlate such tests with the subjective distortion produced. Processing as well as transmission defects can be detected, traced, and corrected, and performance improvements pointed out through such routine checking. Due to the absence of quality performance standards throughout 16-mm recording, processing, and reproducing, such continuous testing is imperative if consistent quality is to be obtained in all 16-mm prints.

It must be admitted frankly that channel checks have been very time consuming in the past and have cut severe inroads into very costly production time when they have been made. Where recording studios have been very busy and their managers much concerned with the operations costs (as most of them are), the natural result has been the infrequent use of channel checks—and then only at the insistence of the recording engineer for the purpose of avoiding equipment breakdown or other serious trouble. The inevitable result has been the gradual yet steady degradation of the quality of recorded sound and of prints considerably below the point to be expected with recording equipment of the design involved.

New test methods arising from radar and similar techniques are beginning to make their appearance, and equipment manufacturers would do well to embrace them by incorporating test provisions into their equipment to make it possible for an equipment operator to check a channel both thoroughly and quickly. One example of such techniques is embodied in the Clarkstan Sweep Frequency Transcription, a Vinylite disk record used for checking audio systems and components.* Two types

* There are two types of disk record cuts, lateral cut and vertical cut. Lateral cut is a type of record cut in which the groove depth and width are substantially constant, and the groove modulation is in the lateral plane of the record, appearing as ''wiggles'' in the helical trace of the recording groove. Vertical cut is a type of record cut—also known as ''hill-and-dale''—in which the groove modulation is in the vertical plane of the record, appearing as variations in groove depth and groove width. In this type of cut there are no ''wiggles'' in the helical trace of the recording groove. Since the stylus used for cutting is essentially triangular in cross section, variations in depth of the groove cause variations in groove width.

of lateral-cut records are available: a 12-inch 78-rpm Vinylite disk for the range of 70 to 10,000 cps, and a 16-inch 33 1/3-rpm Vinylite disk for the range of 60 to 10,000 cps. Both are recorded as logarithmic sweeps from the low to the high frequency; the repetition rate (20 per second) makes viewing on a cathode-ray oscilloscope practicable. The 78-rpm disk is recorded with a 500-cps crossover* frequency; below 500 cps the recording is constant amplitude, above 500 cps the recording is constant velocity. The 33 1/3-rpm disk is recorded with the NAB (National Association of Broadcasters) preequalized characteristic. For frequency identification, marker "pips" are located at convenient frequencies such as 1, 3, 5, 7, and 10 kilocycles; these are of 200-microsecond duration. When these records are reproduced on a good turntable, such as the Western Electric 1304 Type with a reproducer of the Pickering, GE Reluctance, RCA transcription, or Western Electric types, and adjusted to provide a flat frequency characteristic, the electrical signals produced are convenient for testing amplifiers, galvanometers, or other similar equipment. In testing amplifiers a frequency scale may be superimposed on the face of a cathode-ray oscillograph to show the frequency characteristic directly on the face of the tube, thereby avoiding the time consuming and laborious point-by-point plotting of response-frequency characteristics. As the phenomenon is repetitive, a still camera may be used to photograph the image shown on the face of tube if a record is to be placed in permanent file as is usually desired. The traces of this sweep on the face of the cathode-ray tube will also show to some extent dynamic axis shift, harmonic distortion, transient distortion, and a number of other factors that remain obscured when the conventional point-by-point response-frequency characteristic is taken with a sine-wave oscillator.

* Constant velocity recording in a disk record is recording in which the amplitude of the groove is inversely proportional to frequency. For a constant level of signal, the groove amplitude is small at high frequencies and comparatively large at low frequencies. Since the spacings between adjacent grooves is limited, it is necessary to attenuate the low-frequency amplitudes to prevent "cutting over" (the cutting of one groove into another). The point in the frequency range where this change occurs is called the crossover frequency or turnover point; below this point the recording is customarily made at constant amplitude. Constant amplitude recording in a disk record is recording in which the amplitude of the groove is constant for all frequencies. For a constant level of signal, the groove amplitude would be independent of frequency. Reproducing equipment is customarily equalized to correct for the recording characteristics used.

The Clarkstan Corporation is also marketing a signal generator that generates the same form of signal as that produced with the Clarkstan records, thereby eliminating the phonograph and pickup as a source of disturbance in the test signal. Photographs of oscilloscope traces obtained in testing a pickup, and an explanation of the significance of the traces can be found in *Audio Engineering,* October 1947, p. 18, "Analyzing Sweep Frequency Transcriptions," by Wayne R. Johnson.

It must be admitted quite frankly that commercial distortion-measuring equipment is by no means adequate for channel checking, since testing is very laborious and time-consuming and the parameters that are checked are too few, and not related in a sufficiently close manner to the distortion produced by the system when speech, music, or other sounds are recorded. For this reason the most practical test is the recording of test material (such as unrelated words, sounds, noises, etc.) that are similar to some of the sounds that the system is expected to record. Words with sibilants and consonants are most useful for check-variable-area systems; sounds such as piano notes are useful for checking wows and lower speed flutter; and sounds such as violin notes are useful in checking higher speed flutter. Unfortunately the results of such tests are difficult to evaluate numerically.

Among manufacturers of test equipment, there are numerous "overlappings" of apparatus; but, since the design objectives of different manufacturers vary in detail, it is necessary to determine just what a particular instrument was designed to measure in order to interpret the numerical readings obtained from it. For this reason it is rare that the instruments of two different manufacturers of the same apparent type will give equal readings; the differences in readings reflect differences in instrument design quite as much as differences in performance. Since all of these instruments use some form of artificially produced tone which cannot be an accurate simulation of whatever sound is to be recorded, the significance of one instrument in one case may be better than the significance of another; in another case, when music rather than speech is recorded, the reverse may be true. While it may seem trite, it is necessary to repeat that the best test for a system intended to record sound is to record the intended or similar sound. Unfortunately no specific kind of artificially produced tone can accurately simulate all kinds of natural sounds that are to be recorded. Unfortunately, too, the distortion products of practical systems such as variable area, variable density, disk recording, magnetic recording, etc., are quite different in

character and in magnitude. Since the objective of the measuring of distortion is to "show up" the distortion rather than to "hide" it, a method which is designed specifically for "showing up" the distortion produced by one specific recording system will ordinarily become less and less adapted to other systems as it is made more sensitive to the distortion produced by the system for which it was designed. Recommendations should be obtained from the manufacturer; emphasis should be laid upon the time taken by the test and the explicitness of the test results in terms of practical system operation.

Some of the firms manufacturing test equipment and some of their products are:

Hewlett-Packard, Palo Alto, Cal.	Sine-wave audio oscillator Square-wave generator Secondary standard frequency assembly with frequency dividing (for reference frequencies)
RCA, Camden, N. J.	Flutter bridge Cross-modulation test oscillator
Altec-Lansing, Los Angeles, Cal.	Intermodulation test equipment
General Radio Co., Cambridge, Mass.	Harmonic analyzer Standard resistors, capacitors, inductances
Western Electric Co., New York, N. Y. E.R.P. Division	Intermodulation test equipment, Noise-measuring equipment, band filters, etc.
Allen B. Dumont, Passaic, N. J.	Cathode ray oscilloscope

Distortion measurement is certain to advance very rapidly and improve materially in the near future; the American Standards Association has authorized the establishment of a new Sectional Committee (Z57) for Sound Recording. The sponsors of the committee are the SMPE and the Institute of Radio Engineers; the scope of the work covers standards for interchangeability and performance of sound records and sound-recording and reproducing equipment, including, for example: (*1*) the dimensional standards and physical properties of the recording media and the speeds at which they are operated; (*2*) the frequency characteristics and noise and distortion limits of records and recording apparatus; and (*3*) such definitions, terms, symbols, and methods of test as are found desirable. Subcommittee 2 of the Committee has as its scope the development of standard methods for the measurement of recording media; this scope includes methods of evaluating or measuring

distortion in sound recording and reproduction. The proceedings of Subcommittee 2 should be especially watched; it is here that the conflicting design objectives of the various testing methods are to be resolved and measurement methods suited to any sound-recording system regardless of type are to be agreed upon and approved.

Since these discussions are being held at the national level of standardization, technical societies, trade organizations, government groups, and all other constituent organizations involved, will be called upon to resolve the conflicts in design objectives at their specific levels in order to pave the way for effective ASA action.

Semi-portable Equipment

In semi-portable equipment, such as the Maurer Type 162B Recording Amplifier, (Fig. 63), it is not uncommon to have the preamplifier, the

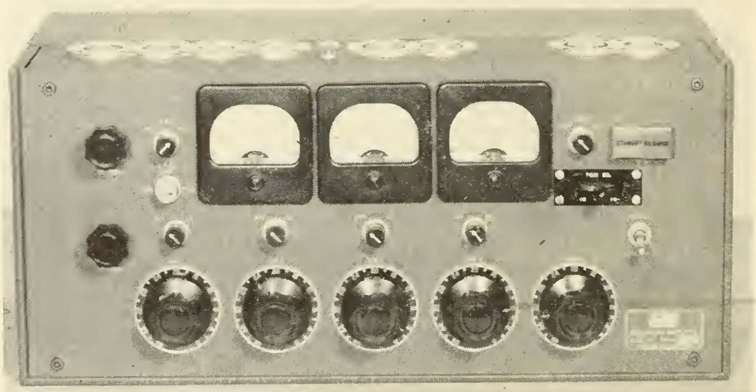


Fig. 63. Maurer type 162B amplifier for 16-mm sound recording. This compact unit includes: (*1*) a single-stage microphone preamplifier (50 ohms input); (*2*) a 3-position dialog equalizer in the 200 ohms output circuit of the preamplifier; (*3*) a 4-position 200 ohms mixer in which the preamplifier output is connected directly to mixer #1; (*4*) a 2-stage intermediate triode amplifier (200 ohms input, 500 ohms output); (*5*) a band-pass filter and a 500 ohms Tee pad master gain control, and a 3-position film loss correction equalizer marked +3, +6, +9; (*6*) an output amplifier (2 stages push-pull) of 50 ohms output impedance. This latter is a variable-gain amplifier that includes: (*7*) a compressor (non-adjustable) that has associated with it the item following: (*8*) a noise reduction amplifier. The power supply unit for this amplifier is in a separate case of about the same size and weight.

main amplifier, the output amplifier, the noise-reduction amplifier, the volume compressor, and the band-pass filters and equalizers incorporated within a single unit assembly. This unit is 20 in. by 10 in. by 11 in. and

weighs 60 lb. The power supply is in a separate case that is connected to it by a cable. The two units are separated to reduce the "stray" hum fields "sprayed" about by the power transformers and by the reactors of the power supply. The maximum over-all gain of the amplifier from the microphone input to the recording machine galvanometer input is in the order of 100 db. The power output is in the order of 250 milliwatts. The total harmonic distortion under operating conditions is well below 2% at full modulation level of the galvanometer. Figures 63A and 63B describe the over-all electrical performance of the Maurer amplifier with different control settings. Figure 64 is the RCA MI-10238 (PA-142) amplifier; this unit is somewhat comparable. The captions associated with the figures provide the pertinent characteristics; the design differences will become apparent when the legends are compared.

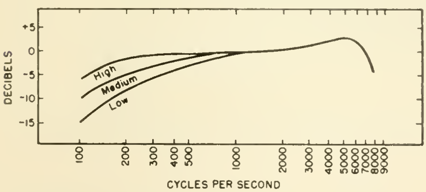


Fig. 63A. Over-all electrical response-frequency characteristic of Maurer 162B amplifier. Film equalizer is on "+3"; the three different settings of the low frequency equalizer are shown.

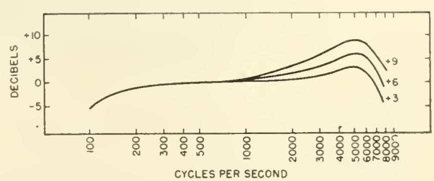


Fig. 63B. Over-all electrical response-frequency characteristic of Maurer 162B amplifier. Low frequency equalizer is on "high"; the three different settings of the film equalizer are shown.

General Characteristics of Amplifiers

It must be recognized that the more versatile an equipment is intended to be, the more costly it will be. Two general classes of equipment are available commercially: permanently installed equipment and semi-portable equipment. In the former, portability and compactness are sacrificed for versatility and superior performance; in the latter, versatility, and—to a degree—performance, are sacrificed for portability and compactness.

Both classes of equipment have many circuit elements in common; in fact, a block diagram representing one is usually applicable to the other. It should be noted, however, that mere size and complexity of itself is no assurance of either versatility or of superior performance in terms of the attributes such as:

1. Signal-to-noise ratio.
2. Absence of distortion.
3. Frequency range (with and without filters).
4. Tonal fidelity.
5. Tonal balance.

Fig. 64. RCA film recording amplifier MI-10238 (type PA-142) main recording amplifier.

The MI-10238 main recording amplifier incorporates the facilities of a main-gain voltage amplifier, an electronic mixer, high- and low-pass filters, a dialog and film-loss equalizer, a ground-noise-reduction amplifier, and a recording power amplifier in a single unit. A telephone jack and associated press-to-talk switch is provided for use of a sound-powered phone. A jack is provided for monitoring with a high-impedance crystal headset. *Normally associated equipment* (*PM-51*) *:* MI-10221-C mixer amplifier ''A'' and ''B'' DC power supplies PR-32 or PR-33 recorder. *Overall characteristics:* Input impedance, 500 or 250 ohms; PA output impedance, 500 ohms; Source impedance, 500 or 250 ohms; PA load impedance, 500 ohms; Overall gain (input and galvo gain controls max., GNR gain min.), 69 db $\pm$ 1 db (may be increased 6 db—see compressor section gain); Overall frequency characteristics, in accordance with current Hollywood recording techniques (+0, $-$1 db overall from 60 to 10,000 cycles without filters); *Power supply requirements:* 250 volts dc at 160 ma (MI-10501-A regulated power supply or equivalent regulated power supply of low internal impedance is essential). 6.4 volts dc at 5.8 amperes. *Physical characteristics:* Length, 26⅜ inches; Width, 19¾ inches; Height, 10⅛ inches; Weight, 88 pounds (approx.); Finish, light-umber-gray wrinkle case, reverse-etched nickel-silver control panel. *Metering:* Internal metering is provided for ''A'' and ''B'' voltage and GNR current. *Voltage amplifier and compressor section:* The compressor offers either linear operation or two electronic positions. The ''De-ess off'' position offers a flat frequency characteristic and the ''De-ess on'' position provides a response in the control circuit which corrects for sibilants (elimination of spectral energy distortion) to provide more natural response for dialogue recording.

All these can be determined only by measurement. Performance claims for apparatus, the performance of which has not been measured, are sheer guesswork and have little meaning. Reputable manufacturers customarily measure every piece of equipment offered for sale for each performance characteristic claimed. Such production test records are accumulated for extended periods by the manufacturer. These data are usually available on the request of the equipment user.

Noise Reduction Principles

If a piece of clear film is run in a sound projector, noise due to dust, dirt, irregularities, and scratches on the film is heard in the loudspeaker. If film is used regularly in projection, it is found that the noise produced increases with wear, becoming very annoying as the film acquires more scratches and dirt in its many trips through the projector. If the clear film is kept stationary in the projector, and the amplifier turned up to its maximum gain, considerable hiss is heard from the loudspeaker of the projector; if the light beam of the projector is blocked with an opaque card, the hiss previously heard is reduced materially. The hiss that was eliminated was due to the light falling on the photocell and its effect upon the input circuit of the reproducing amplifier; the noise remaining is substantially the noise produced by the amplifier itself.

With good amplifier design, it is possible to reduce the amplifier hiss to a negligible amount when reproducing good sound film; however, to reduce the hiss from the photocell circuit and the noise resulting from the random dust, dirt, irregularities, etc. requires masking of the film. Since the noise produced is a function of the light transmitted to the photocell, it is apparent that this light flux should be reduced to a minimum. Because the variations in light cause the electrical output of the photocell, it is apparent that the problem is to keep the light variations at a maximum while keeping to a minimum the average light transmitted. This is accomplished by a process identified by a number of different names, such as noise reduction, noiseless recording, ground-noise reduction, anti-ground noise system, etc.

The principles of noise reduction in photographic recording were appreciated early. Patents were issued to Adsit, an independent inventor, by the U. S. Patent Office shortly after World War I; this was several years before sound film was commercially introduced successfully in 1928 by Warner Brothers. Subsequently, patents were issued to Sacia of Western Electric on an early form of control track (predecessor to the control tracks used in *Fantasia* and in the Bell Telephone Laboratories

stereophonic demonstration). Still later, numerous patents were issued in different countries of the world; some of those filed in the United States gave rise to much expensive litigation in which the fate of many millions of dollars depended upon the outcome.

Today all modern recording equipment utilizes the noise reduction principle; in all arrangements the average transmittance of the positive film is made approximately equal to the modulation. This is accomplished by automatically "blacking-in" the sound track area not used for modulation in a variable-area film. Thus, on a positive, the sound track is almost entirely opaque when there is no modulation as only a small portion of the width is needed for the modulation; when full modulation occurs, the sound track has maximum transmittance as full width is needed for the modulation. At modulation levels between these two limits, the average transmittance is kept approximately proportional to the modulation by means of the noise-reduction amplifier (often called a bias amplifier) and its adjuncts.

If the signal-recording and noise-reduction functions are thought of as two separate functions, one means is used to record the signal and the other to record the noise-reduction current. The wave form of the signal should be undistorted; the wave form of the noise-reduction current is altered by rectification. The rectifier is connected to a filter circuit, with the charging characteristics of the filter determining the attack time of the noise-reduction system, and the discharge characteristics of the filter determining the decay time. Mathematically, the bias current provided at the output of the bias amplifier is a rectified envelope of the signal current. In the design of practical equipment, the input to the bias amplifier "bridges" the signal circuit, being connected in such manner that it does not appreciably alter the transmission characteristics of the circuit, and draws a negligible amount of energy from it, *e.g.*, 5% or less.

A typical commercial design would include: (*1*) an amplifier portion to increase the audio frequency energy level to a convenient point, (*2*) an audio rectifier, (*3*) a filter circuit for the control of charge and discharge times, and (*4*) an output d.-c. amplifier tube. In such a commercial design it is customary to provide maximum d.-c. output from the bias amplifier when no signal is present, and minimum d.-c. output when maximum signal is present. In this manner, failure of the bias amplifier will cause merely the omission of bias but will not distort the recorded signal.

The bias amplifier is usually actuated by the signal being recorded. The unidirectional current output of the noise-reduction amplifier may

be applied to the galvanometer itself (Maurer equipment) or to a pair of cooperating shutters (older RCA equipment). In both cases the signal proper is applied to the light modulator. Figure 65 shows the bias form of bilateral sound track (Maurer), and Figure 66 shows the shutter form of duplex sound track (RCA). For convenience, both the negative and the positive forms of sound track are shown.

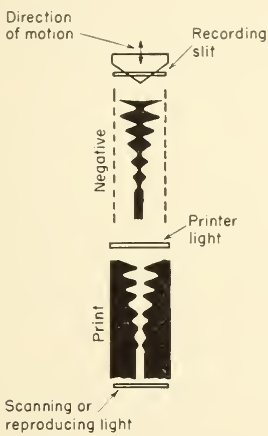


Fig. 65. Bilateral variable-area sound track—galvanometer biased for noise reduction. Vertical motion of the triangular light beam across the slit due to signal current in the galvanometer provides modulation of the track. Pulsating bias current also applied to the galvanometer alters the average light transmission by shifting the mean position of the triangular light beam upward or downward in accordance with the signal amplitude.

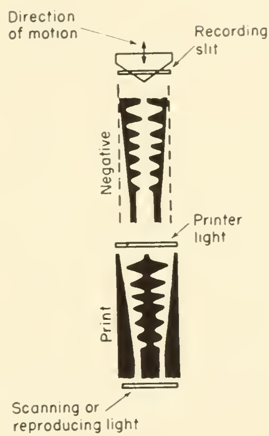


Fig. 66. Duplex variable-area sound track—shutter biased for noise reduction. Vertical motion of the triangular recording light beam across the slit due to the signal current in the galvanometer provides modulation of the sound track. Horizontal motion of the shutter vanes (opening and closing) across the slit due to the pulsating bias current alters the mean light transmission in accordance with the signal amplitude.

If a direct-positive sound track is to be recorded, the transmittance of the sound track must be made a minimum for zero modulation; this is accomplished by reversing the direction of the bias current flow through the galvanometer or shutters by means of a reversing key or switch and by making certain other adjustments, such as changing from the negative-recording aperture to the positive-recording aperture. Most 16-mm equipment made prior to World War II does not have provision for direct-positive sound tracks.

If a negative sound track is to be recorded, the transmittance of the sound track must be made a maximum for zero modulation; this is accomplished by moving the bias key or switch in the direction opposite to that used for direct-positive recording in order to reverse current polarity, and by changing to the negative aperture in the recording machine.

Noise Reduction Design Considerations. When a signal is suddenly applied to a recording system, the amplified signal appears at the galvanometer before the bias current appears. The time of transmission of the bias is longer than the time of transmission of the signal proper because of the delay introduced by the bias amplifier.

The starting-time delay is known as the bias opening, attack time, or bias unlocking time. Although this time delay may be the source of audible distortion for steep wavefront sounds (such as pistol shots), commercial equipment used to record conventional sounds will show little audible distortion. The attack time of a bias amplifier depends upon the designer's choice; wide differences of opinion exist among designers as to the optimum time. One commercial design has an attack time of 20 milliseconds; many designers think this time rather long.

When the signal actuating a bias amplifier ceases, the bias current decays. To avoid audible distortion, the bias closing (or decay) time is made quite long compared with the opening time; it is 70 milliseconds for the unit whose attack time is 20 milliseconds. Since the closing time for a noise-reduction system is not critical, it is not made adjustable.

The amplifier portion of the "front end" of a bias amplifier is customarily designed with a maximum gain in excess of that actually required. A gain control in the form of a screwdriver slot arrangement. is provided to reduce the gain to the desired amount. The attack time of the bias amplifier depends upon the slope of the signal voltage – bias current curve and upon the gain of the "front end" of the bias amplifier. The slope of the signal voltage – bias current curve depends upon the design constants of the unit; the gain of the amplifier is usually set by means of the screwdriver slot gain control so that full unlocking is effected when a sine wave tone of 60% modulation at 1000 cps is applied. The relationship of bias voltage to applied signal voltage is quite linear up to complete unlocking. Ordinarily, the gain-setting adjustment is made during bias amplifier manufacture and need not be altered during use, since the amplifiers are quite stable in operation and the recording machines with which they are used are quite consistent in sensitivity of both the galvanometer and of the cooperating shutters—if used.

An initial bias or margin adjustment is also provided. This adjustment may be the resistance variation of a cathode bias resistor on the output tube; it is customarily set so that when no modulation is present, the d.-c. output current through the biasing shutter or galvanometer will provide a transparent track width of about 0.003 in. to 0.005 in. as seen on a positive film. Margin is provided to offset the starting-time delay of the bias amplifier when an actuating signal appears in the system. Ordinarily, once the milliammeter reading for the desired margin is determined, it is merely necessary to set the margin control for the correct current; readjustment is rarely required.

In the design of bias amplifiers, some engineers prefer half-wave rectification of the audio signal, while others prefer full-wave rectification. Since it is well known among design engineers concerned with sound film recording that the pressure wave of the average sound wave shows a much sharper rate of pressure rise that the rarefaction wave, half-wave rectification is theoretically preferable despite a more difficult filtering problem, because of the more rapid rate of rise in bias current that can be obtained when the microphone and the amplifiers are properly poled throughout the recording system. Other engineers take the view that such poling is difficult if not impracticable, and therefore prefer the full-wave rectifier with a simpler filter; this viewpoint is valid when, as is often the case, the phase distortion in the system is quite large.

The shortcomings of bias amplifier designs were appreciated early, and many efforts have been made to overcome them. Generally speaking, the improvements have been made in two general directions, one to speed up the action of the bias amplifier attack and the other to compensate in some fashion for the delay that inherently exists. The improvement in the former direction has led to more complex filters, to better regulation of the plate voltage supply energizing the bias amplifier circuits, and to the use of an ultrasonic carrier that is modulated by the applied signal. The use of the ultrasonic carrier reduces the size and the time constants of the filter needed; other advantages, such as altering the slope of the signal current – bias voltage curve at the starting threshold can be derived from the modulating and demodulating functions. No doubt the future will see the application to this problem of the gate and the pulse techniques, principles that proved so valuable to the performance of radar equipment during the recent war.

There is one fundamental method to compensate for bias delay: that is to eliminate the effect of the delay either by (*a*) delaying the

signal, or (*b*) providing bias anticipation. Filters and other artificial delay networks can delay a signal for short periods. Unfortunately, such networks usually result in the noticeable distortion of transient sounds (such as dancing taps) when even relatively short delay times are involved. Other forms of temporary recording with a small storage time may also be used, the signal being, in effect, re-recorded to the film recorder after the required delay interval. Such temporary methods usually involve a noticeable loss of quality. Continued progress is being made in these directions.

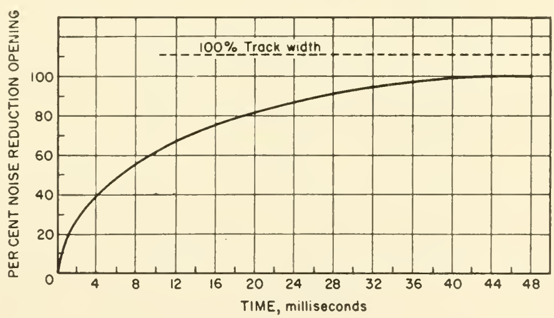
Within recent years, when even steep wavefront sounds are expected to be recorded with no audible distortion, bias anticipation has been used with quite successful test results. One effective yet complex method has been to set up a separate microphone for the anticipation circuit; this microphone is located between the recording microphone and the sound source. In this manner, the sound from the source strikes the anticipation microphone the desired number of milliseconds before it reaches the signal-recording microphone. The chosen anticipation time is just a little larger than the delay occurring in the bias amplifier circuit. In practice, both microphones are suspended on the same microphone boom. As has been indicated, the anticipation microphone and its amplifiers serve to energize only the bias amplifier, the recording microphone providing the signal to the light modulator in the usual manner. Anticipation has not been widely used; the disadvantage of the additional complication in the making of the original sound record can only be overcome when the "normal" distortion of commercial photographic printing is reduced to the point where the excellence of such records can be appreciated by being heard.

With conventional 16-mm noise reduction equipment the improvement in signal-to-noise ratio that is obtained is from 5 to 10 db. As is apparent, the actual results depend upon how well the film is processed quite as much as on how well the noise-reduction equipment functions electrically. Noise-reduction equipment aids primarily in reducing the noise effects of dust, dirt, oil, and light scratches picked up by the release print during projection; it does not alter in any way the noise recorded upon the film or the noise of the film itself.

Distortion Testing of Noise-Reduction Equipment. Since no two noise-reduction equipment designers make the same assumptions and compromises in their designs, the primary test of the equipment rests

in the relative seriousness of the distortion produced compared with the reduction in noise produced. A simple method of checking this qualitatively is to record some repetitive material in the ordinary way, and to make one subsequent record with the signal on and the bias switched off, and a further record with the signal switched off but the bias switched on. A direct A-B comparison between the record with bias and without bias quickly indicates the extent of the distortion introduced by the bias equipment. Listening to the bias record will indicate the distortion produced in the bias record alone. In playing back these records it will be found advantageous to increase the gain of the reproducing equipment up to the point where the sound level from the loudspeaker is as great as the largest likely to be found when the film will be projected.

Fig. 67. Opening characteristic of RCA biased galvanometer with RCA MI-10236 noise reduction amplifier. Noise reduction opening time is assumed to be the time for 90% of full noise reduction opening.



This distortion can usually be heard, and although it is small it is still significant. An equipment owner will do well to make such a test periodically along with other periodic equipment tests.

Figure 67 is the opening characteristic of an RCA biased galvanometer actuated by an RCA MI-10236 noise reduction amplifier. When so used, a bilateral form of sound track is produced. Figure 68 is an electrical schematic of the amplifier.

Volume Compression

Principles

Since the volume range of a full symphony orchestra is about 80 db, and the volume range of a good 16-mm projector is only about 25 db, it is evident that something has to be done to the volume range of the symphony orchestra if it is to be brought within working range of a 16-mm projector. Fortunately, in most cases, 16-mm recording equipment is not often called upon to record a symphony orchestra, and the problem

of compressing the volume range by 55 db does not often arise; however, cases do arise where the volume range of the sound at the microphone is greater than can be accommodated, and something has to be done about it. Should a film with a volume range wider than that of a projector be run in the projector, the low-level portions will be below the general noise level and will therefore be inaudible or unintelligible.

When a sound recordist or mixer man operates his equipment, one of his chief duties is to make certain that the loudest sounds to be recorded are so controlled in recording that they are not "overshot" beyond the full modulation capabilities of the recording machine. If the volume

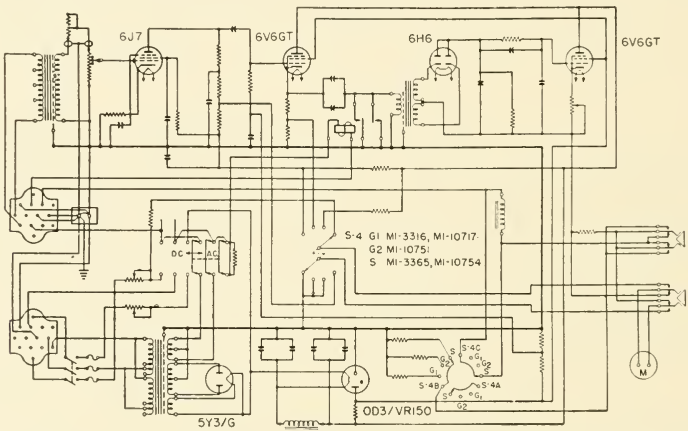


Fig. 68. Electrical schematic of the RCA MI-10236 noise reduction amplifier. This amplifier has the ability to respond to nonsinusoidal wave forms such as "spikes" (pulse signals of short duration) to a degree approaching its sine-wave response. Such an amplifier is said to have good peak-reading ability.

of the sound to be recorded changes slowly, and the effect desired is one of relatively constant volume, the mixer man moves his "mixer pot" to compensate for the changes in sound level. Such manual control is quite effective in recording the speech from an experienced commentator. With an untrained speaker, however, even the best such recording often proves unsatisfactory—particularly under unfavorable conditions of reproduction, such as reproduction in an acoustically poor auditorium.

It was found that one of the differences between "a good recording voice" and "a poor recording voice" lies in the amplitude of short period peaks produced in the voice. A "good recording voice" is "easy to record" because it has few if any short-period peaks; those that are present occur infrequently and have a small peak amplitude when compared

to the average of the speech wave. It is also an important fact that a voice with short-period high-amplitude peaks is not as clear and intelligible and does not carry as well as a well-trained voice that is relatively free of such peaks; such short-period peaks actually reduce the effectiveness of the speaker and occur so rapidly and are of such short duration that the reaction time of the mixer man is too slow to catch them; also, they happen so quickly that the mechanical mixer controls could not respond quickly enough to the changes. For most voices, certain definite improvements in quality and in the reduction of noise can be obtained by providing an amplifier that will automatically reduce the volume range. The principle of volume compression is now so well established that it is provided for in all modern 16-mm recording equipment. Conventional volume-indicator meters, such as the American Standard VU meter, do not indicate short-period peaks of very short duration; for this reason, films recorded without volume compression either "sound low in volume" despite the fact that the peaks are either 100% modulated or "overshot" because the peaks are overmodulated and therefore distorted. Short-period peaks add little or nothing to the expressive dynamics of speaking, but are, rather, caused by a lack of breath control or other shortcomings on the part of a speaker.

The manner in which volume compression should take place depends upon the over-all overload characteristics of the recording system. Ideally, it might seem desirable to reduce the system amplification suddenly just before the overload point is reached. Practically, however, the compression characteristic chosen depends upon the kind of sound to be recorded and upon how "gracefully" the recording system to which it is to be applied overloads. In variable-density recording—in which overload is more gradual than in variable area—compression may be set to begin at a higher relative modulation level; there is some curvature at the extreme ends of the exposure *vs.* print-transmission characteristic, which makes the overload characteristic more gradual and more "graceful." In certain respects the overload characteristics of variable-density recording may be considered similar to the gradual overload characteristics of a triode class A-B_1 amplifier, whereas the overload characteristics of variable-area recording are more similar to a beam-power tetrode push-pull amplifier of the same wattage rating with appreciable inverse feedback. The overload characteristic of the latter "breaks" more sharply. It is often said that a limiting amplifier is used for variable-density recording while a compression amplifier is used for variable area.

A well-designed limiting or compression amplifier should merely limit or compress. It should not change the "balance" of the recorded sound if the recording is compared with a recording made without limiting or compression. An audible change in balance is a change in spectral sound energy balance; such a change is referred to as spectral energy distortion. Since recording equipment is customarily equalized in a definite manner, the use of limiting or compression amplifiers should not alter the equalization. Customary equalizing attenuates bass tones appreciably and accentuates high frequencies. As has been pointed out, the response-frequency characteristic of a recording is "tipped upward" rather than being flat.

In practice there is little difference between a limiting amplifier and a compressor amplifier other than the threshold volume at which the

TABLE XVII

Optimal Compressor Characteristics (RCA)

Attack time	0.7	millisecond
Release time	0.5	second
Threshold volume	10	db (under full modulation of the light modulator
Compression ratio	20	db into 10 db

limiting or compressing action begins. The important characteristics of a compressor amplifier are:

1. Attack time—the time required to reduce the gain.
2. Release time—the time required to restore the gain to normal.
3. Threshold volume at which the action begins.
4. Shape of the input-*vs.*-output curve after compression begins.

Because of the sharper overload characteristics of the variable-area recording method, the threshold level at which compression begins is customarily set appreciably lower than with variable density.

As is the case with the design parameters for noise reduction, there are as many selections as there are designers. Some recent data on optimal characteristics as a result of listening tests on RCA equipment are shown in Table XVII.

Figure 69 shows a compression curve as used in a typical compressor. This characteristic will give substantially greater average modulation on most voices that may be recorded. (Further data may be found in the references indicated at the end of this chapter.)

Compressors are used wherever a limitation in volume range can pro-

duce an effective increase in intelligibility. They are used widely in broadcast stations because of the increase in effective station-coverage area and the improvement in effective signal in the area covered. The characteristics of such compressors are similar to those used for sound-film recording. Following in Table XVIII are the published characteristics of the Western Electric 1126C Peak-Limiting Program Amplifier.

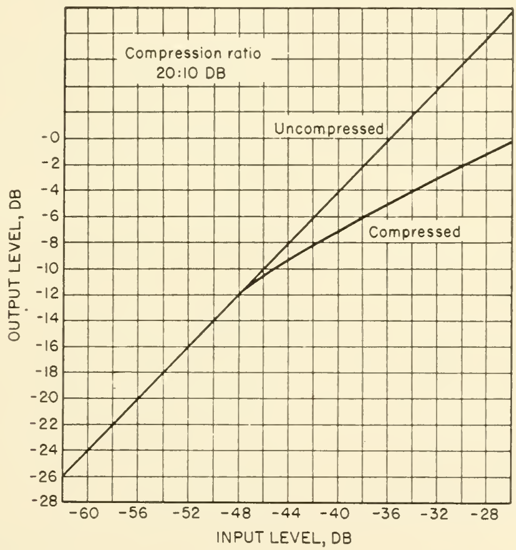


Fig. 69. Volume level compression characteristics of a typical compressor.

Attack Time

The choice of attack time in a volume compressor depends to a great extent upon the bulk and weight of apparatus and the circuit complexity that can be tolerated. Much commercial equipment (RCA) has been using an attack time of 2 milliseconds for several years. It has been found possible to reduce this attack time to 0.7 millisecond without undue increases in the accuracy of the tube balance required or in the stability of the power supply associated with the compressor. When a compressor has an attack time of as little as 0.1 millisecond, the power supply must be accurately voltage-stabilized; to accomplish the desired objective the power supply must be designed as an integral part of the compressor. A compressor such as the Western Electric 1126C uses five tubes in the power supply alone, while seven more tubes are used in the compressor amplifier proper. Although this seems like quite a large number of tubes

for just a volume compressor, the results of its use are so evident, that its desirability cannot be questioned.

When a compressor is connected in a transmission circuit, such as in 16-mm recording equipment, it has the tendency to "flatten out" the

TABLE XVIII

Characteristics of Western Electric 1126C Amplifier

Maximum gain	51.5 db
Source impedance	600 ohms (circuit not balanced to ground)
Load impedance	600 ohms (circuit not balanced to ground)
Output power	+ 25 db maximum when gain reduction starts (output attenuators omitted)
Output noise	69 db below output level when gain reduction starts
Input-level range	− 26 dbm to + 24 dbm (single frequency tone)
Output-level range	− 4 dbm to + 25 dbm (single frequency tone)
Output distortion	
For program	Less than 1% for all operating conditions up to 5 db compression
For single frequency tone	Below compression, less than 1%; for 5 db compression, less than 1% for frequencies above 200 cps and not more than 1.75% for frequencies as low as 50 cps
Frequency response	Flat within ± 1 db over the range 50 to 15,000 cps
Compression ratio	10: 1 (10 db input increase results in 1 db output increase above the point at which gain reduction starts)
Attack time	Approximately 0.1 millisecond
Recovery time	Variable in 5 steps of 0.2 second each from 0.2 to 1 second. Optional adjustment permits variation from 0.1 to 0.5 second
Weight	49 pounds
Power supply	105 to 125 volts, 0.7 ampere, 50–60 cycles alternating current
Dimensions, inches	19 1/4 wide, 19 1/4 high, and 6 3/4 deep (for 19-inch relay rack)
Price	About $500

signals transmitted, since it tends to limit or compress only those components that are above its threshold. One operating result of this flattening effect is that if a portion of the transmission range is equalized ahead of the compressor by cutting the lows for dialogue equalization, for example, the compressor would have the effect of reducing the low-fre-

quency attenuation due to its flattening effect. Similarly, as most of the high-frequency components do not have the peak level of the short-period sounds that are above the threshold and are therefore not limited by the compressor action, their relative attenuation is likewise reduced due to the flattening effect of the compressor. Thus, in one sense, a compressor tends to defeat the purpose of equalizers by introducing spectral energy distortion; the amount of the effect depends upon the amount of compression, the nature of the compression (input-output level characteristic), and the character of the sound compressed. For that reason, the use of compression affects the location of equalizers in the recording system, and, as a result, equalizers may no longer be used indiscriminately between the output of the microphone and the input of the light modulator of the sound-recording machine.

Compressor action tends to alter voice quality for the same reason that it tends to defeat the purpose of equalizers. Since declamatory speech has relatively fewer low-frequency components and is therefore pitched higher than speech at more normal levels, compressor action tends to "flatten out" this too by raising the relative level of the lower register and making the pitch of the voice sound lower. Whether this is desirable or not depends upon the purpose of the recording. Equipment designers have different ideas on this subject just as they have different ideas about the timing characteristics of compressor and noise-reduction equipment. In most commercial designs, the compressor characteristics as well as the noise-reduction timing and frequency characteristics are fixed, and cannot be changed very readily. This is particularly true in semi-portable equipment, in which weight and size must be given preference over theoretically desirable performance characteristics.

Spectral energy distortion in a compressor used in 16-mm sound-recording equipment, if allowed for in the design, usually takes the form of reducing both the low- and high-frequency responses of the audio-rectifier portion of the compressor equipment. Again, the amount of correction obtained is a matter of designer's choice and will vary from one piece of equipment to another. Since one of the undesirable effects of spectral energy distortion in variable-area recording has been to over-accentuate the sibilant sounds, the alteration of the response-frequency characteristic of the audio-rectifier portion of compressor equipment is often referred to in the vernacular as a "de-esser" circuit. Figure 70 shows a frequency characteristic of the compressor audio circuit and of the audio-rectifier equalizer response.

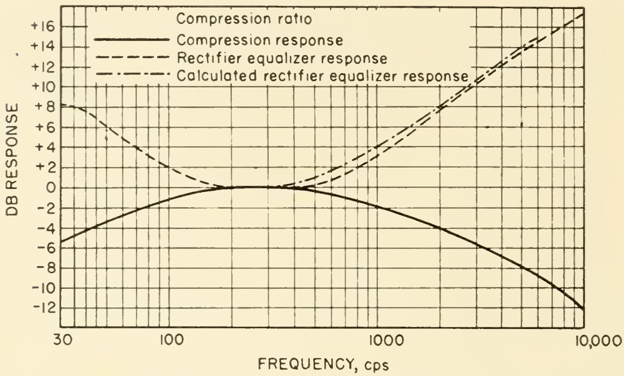


Fig. 70. Response-frequency characteristics of the compressor signal circuit and compressor rectifier-equalizer control circuit of an RCA compressor.

In a complete recording system, the present trend in design is to locate the equalizer for slit loss, film loss, and for similarly fixed losses *after* the compressor, and to locate the other so-called variable losses, such as voice effort compensation, microphone compensation, and the like, *ahead* of the compressor. Regardless of the type of equalization used and regardless of its position, it is of utmost importance to know just which losses occur, just where they occur, and to equalize for them accordingly if consistent and good quality sound is expected from 16-mm release prints. In the final analysis, it is the release print that is run in the projector before the intended audience and it makes little difference to that audience where the quality was lost if it does not appear on the particular release print being heard.

Figure 71 is a block diagram of a complete Western Electric recording channel as used for 16-mm recording. Figure 71A is the RCA PM-

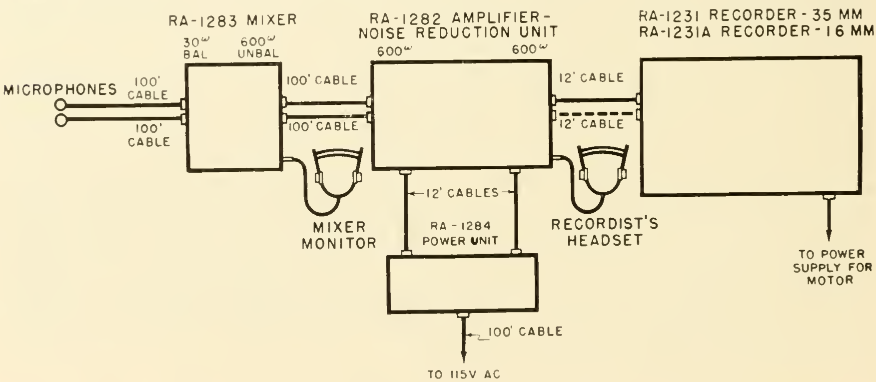


Fig. 71. Block diagram of Western Electric type 300 recording system.

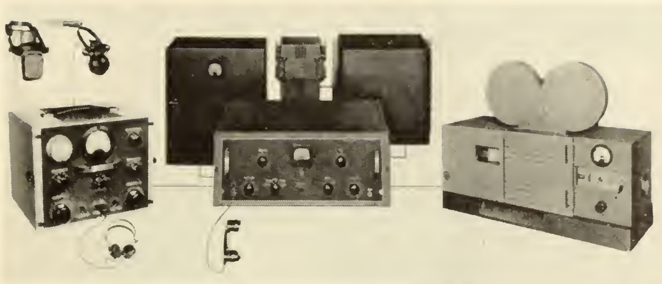


Fig. 71A. RCA PM 51B recording system. Consists of KU-3A unidirectional microphone (left); KN-2A pressure microphone (right); PA-128 mixer-amplifier (left); MI-3456B headphones; PX1 plate power supply unit (left); PX-4 low voltage supply unit (right); MI-3530 voltage regulator (center rear); PA-142 main amplifier; MI-2040AS sound powered interphone; PR-32 16-mm recording machine.

Technical data for PA-128 mixer-amplifier. *Radiotron tube complement:* 5 RCA 1620's. *Power required:* A supply—6.3 volts dc at 1.5 amperes; B supply—250 volts dc at 10 milliamperes. *Input:* Source impedance, 250 ohms or 30 ohms; Input impedance; unloaded transformer (balanced). *Volume indicator meter:* High speed VI meter. The DB RANGE switch adds 20 db to the range of this meter through 5 steps of 4 db each. *Meter calibration adjustment:* 25,000-ohm linear-taper carbon potentiometer. Screwdriver adjustment by removing chassis from case. *Output:* Load impedance, 500 ohms or 250 ohms; Output impedance, 500 ohms or 255 ohms (balanced); Rated power output, 0 db (0.006 watts) with less than 1% rms distortion from 100 to 7500 cps. *Gain:* 57 db measured at 1000 cps from 250-ohm source to 500-ohm load. *Noise level:* – 65 db input terminated with 250 ohms, output loaded with 500 ohms. *Switches:* Oscillator, four circuit, two-position rotary switch (S-1); Equalizer, single circuit, five-position rotary switches, two provided (S-2 and S-3); Talk back, push button switch (S-4); Db range, single circuit six-position rotary switch (S-5); A voltage, DPDT push button switch (S-6). *Monitoring facilities:* Jacks are provided for monitoring the output of the recording amplifier by means of headphones (such as RCA MI-3456 high fidelity phones). (J-5 and J-6.) Headphone volume level is controlled by the monitor control mounted in the rear of the amplifier. *Microphone:* Mounted in upper left of front panel to permit (by pressing the TALK BACK switch) conversation between the mixer and recordist. *Mixer gain controls (two):* 50,000-ohm logarithmic-taper carbon potentiometer. Knob adjustment from front of panel. *Finish:* Case, light gray wrinkle; 6-inch decorative band around case—dark gray wrinkle; Panel, light umber gray lacquer. *Dimensions and weight:* Height 9½ inches; Length 12½ inches; Depth 10½ inches; Weight 27 pounds.

51B recording system. Figure 71B is the Maurer recording system. Figure 71C is the Maurer 16-Mm film phonograph.

Future Trends in Noise Suppression

Despite the rather chaotic situation resulting from the lack of performance standards for 16-mm sound projectors and films, there are evidences of a "settling down" of performance and of response-frequency characteristics in the better grade machines. In the Bell and Howell, for example, the slit size was reduced from 1 mil to approximately 0.7 mil several years ago. Since the high-frequency performance of the ma-

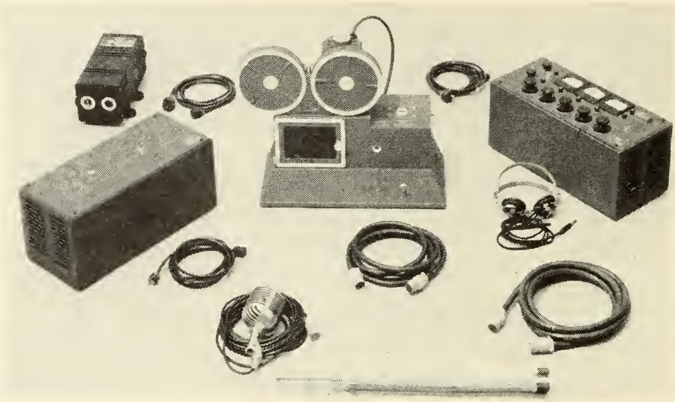


Fig. 71B. Maurer 16-mm sound recording equipment (without carrying cases). Consist of Sola voltage regulator, Maurer sound recording machine, Maurer recording amplifier, Maurer power supply, Shure microphone, microphone tripod, Western Electric monitoring headphones, and interconnecting cables. The equipment shown is completely energized from a 117-volt 60-cycle single-phase power line without batteries of any sort.

chine was noticeably improved by this manufacturing change, it was necessary to improve the performance of other parts of the machine. The major improvements were a reduction of flutter (which is more perceptible when the frequency range is wide), a reduction in the microphonic sensitivity of the exciter lamp and its associated optical system, and a reduction in noise and distortion of the amplifier. If the cheap "box-type" loudspeaker that is still used is replaced by a good loudspeaker, such as the Altec 604B or the Western Electric 755A with an appropriate housing, the performance of this machine is surprisingly good when a really good print is used. The performance has but one

significant defect compared with the reproduction of conventional 35-mm prints in a 35-mm theater: the noise level produced is noticeably higher by comparison. Admittedly, the frequency range is more limited, but this shortcoming is minor compared with the noise difficulty.

There are two general avenues of approach to the problem of noise

Fig. 71C. Maurer 16-mm film phonograph (with cover removed). Like other Maurer 16-mm machines, this is driven by a 117-volt 60-cycle single-phase synchronous motor. Either standard or nonstandard emulsion position films can be scanned; the film is run from right to left for one emulsion position, and reversed for the other. The input of the self-contained single-stage preamplifier in the machine is fed from an IP-37 blue-sensitive photoelectric cell, which may be replaced by a conventional #918 red-sensitive photocell if desired. A power supply similar to that shown as part of Figure 71A supplies all current required from the power line for energizing the exciter lamp from rectified and filtered current, for energizing the preamplifier (including rectified and filtered current for its heater), and for furnishing polarizing voltage to the photocell.

suppression: (*1*) the improvement in the inherent performance of the apparatus component or material involved, such as the reduction in grain size of the films, reduction of film fog, removal of dirt from the processing of all films, reduction of amplifier noise due to hum, noisy resistors and

capacitors, noisy microphonic tubes, and the like, and (*2*) the modification of the recording and reproducing systems to "fit in" the sound to be recorded with hearing-perception characteristics such as those described in the preceding chapter.

In the recent past, the major changes in equipment have been related more to the first avenue than to the second. We are now beginning to reach the point of diminishing returns, however, and large increases in effort produce far smaller increases in quality improvement. For this reason much more attention may now be given to the second avenue of attack. This trend will no doubt continue into the future since it is here that the possible results can be justified by the effort required to obtain them.

One of the first such successful steps was the introduction of compression and limiting. In the commercial equipment that was manufactured, the small increase in distortion that resulted from the use of the compressors and limiters was more than offset by the improvement in intelligibility of the intended signal. It cannot yet be unequivocally stated that the application of compression to 16-mm sound recording has been an unmixed blessing. A source of primary magnitude appears to be the intermodulation of the variable spectral energy distortion with the variable distortion encountered in the photographic steps of the process, especially in developing. In variable-area 16-mm recording, excessive sibilant distortion has occurred especially when pressure-type microphones with "un-smooth" response-frequency characteristics have been used. In practice, this problem has often been sidestepped by the use of a ribbon-type microphone. In certain extreme cases, serious distortion has occurred with, *e.g.* an RCA 77D microphone connected for either dynamic or cardioid pickup; the distortion was reduced merely by connecting the same microphone for ribbon (bidirectional) pickup. When this difficulty is encountered in practice, dynamic microphones seem to be the worst offenders, hybrid types such as the commercial cardioids seem to be lesser, and ribbon types seem to be the least. The relative location of high-frequency response peaks and of the smoothness of recording galvanometer, microphone, and of the cutoff characteristics of equalizers appear to be significant factors. When all factors are working smoothly, in equipment with very low intermodulation products, compression is quite advantageous, especially when films are projected under a wide variety of acoustic conditions.

Fortunately, the recent war has accelerated the collection and appli-

cation of hearing-perception data that arose from the truly remarkable improvements in hearing aids, intercommunication systems, and battle-announce systems. All such equipment was not only mechanically rugged and quite consistent in performance, but the transmitted sounds were intelligible and very useful under the very adverse high noise level ambients common in such services. It is only reasonable to expect to see such data utilized in the sound transmission systems in 16-mm sound films; the methods no doubt will be characterized by a wide variety of principles.

A recent development that is likely to leave its mark is the dynamic noise suppressor of H. H. Scott.* As now manufactured, this electronic arrangement provides dynamic adjustment of the audio pass-band from approximately 2 1/2 octaves minimum to the full audio range as a maximum. It can be readily redesigned specifically for 16-mm sound film uses and can be applied to recording amplifiers as well as to reproducing amplifiers. With this arrangement, another step is made in the direction of limiting the amplifier passband to that dictated by the signal itself, thereby eliminating such response of the amplifier at either end of the audio spectrum where no useful signal is being transmitted. Such methods take account of the fact that the transmission range should be narrow when the signal level is low, and that the transmission range may be widened as the signal level rises. Similar developments have occurred in the design of radio receivers; in one by Farrington,** for example, the width of the audio pass-band in the intermediate frequency amplifier was made dependent upon the strength of the signal. The ability of such a radio receiver to reduce ''monkey chatter'' caused by intermodulation of radio signals on adjacent channels is truly remarkable when the receiver is tuned to a weak distant station with an adjacent-channel local station operating. Similarly surprising reductions in intermodulation distortion should result from the application of similar audio techniques to 16-mm films and equipment. Where the Scott dynamic noise suppression arrangement might be used in re-recording a release sound negative, for example, the maximum frequency range would still be limited by a fixed bandpass filter such as one of those specified for the preferred frequency ranges. The particular preferred range chosen would still represent the widest range practicable for the

* Scott, H. H., 385 Putnam Ave., Cambridge, Mass.

** Farrington, J. F., ''Receiver with Automatic Selectivity Control Responsive to Interference.'' *Proc. I. R. E.*, April 1939, p. 239.

average acoustic condition under which a print would be projected. Dynamic noise suppression in the recording might be a sufficient improvement for all but the very worst cases; in such cases dynamic noise suppression might also be used in the projector amplifier.

More recently, a number of studies have been reported in the *Journal of the Acoustical Society of America** on the subject of "peak clipping" of speech and its effect upon intelligibility and distortion. From the results reported, it would appear that the amount of "peak clipping" that would be desirable in a practical case will depend upon the relationship of quality and intelligibility. From data presented up to this point, it would appear that "peak clipping" to the extent of 10 db might be suitable for cases where intelligibility is at a premium; 6 db might be applicable in other cases.

Another development reported by Westmijze** of Holland seems to show promise where noise levels are particularly high from the film. The method is an outgrowth of the pulse techniques common in radar; in its application to reproducing 16-mm films it may be said to "sample" the recorded trace at a (relatively) very rapid rate and to discriminate against noise by the techniques of wave-shape control also common in radar. The effects of gross occlusions of dirt, scratches, and similar irregularities can be reduced by this method; for minor occlusions the distortion, which is similar to that produced by peak clipping seems somewhat high.

It is essential that the best practicable signal-to-noise ratio be obtained when a film is projected for an audience because of the improvement in the attention potential when extraneous noise is made a minimum. In the future it may be desirable to use some kind of waveform control in addition to pass-band control. It is difficult to predict at the moment what the forms may be. The problem will probably resolve itself into a comparison of the relative costs of incorporating such controls in projectors, of improving sound optical systems, amplifiers, etc, or of incorporating equivalent improvements in the recording equipment in such manner that the optimal results will occur on the films. Since the number of sound projectors in use is quite large and machines are low in price compared with recording equipment which is limited in supply and

* Kryter et al, "Premodulation Clipping in AM Voice Communication." *JASA*, Jan. 1947, p. 125.

** Westmijze, W. K., "A New Method of Counteracting Noise in Sound Film Reproduction." *JSMPE*, Nov. 1946, p. 426.

high in price, it would seem the better part of wisdom to incorporate all possible improvements into the sound-recording channel. No doubt some inexpensive electronic improvements will find their way into sound projectors; to be worthwhile, the ratio of result to cost must necessarily be high.

Monitoring

It is apparent that sound recording as it is actually practiced for 16-mm sound films requires accurate control for determining just what is being recorded on the film and just how it is being recorded. To determine what is being recorded, the recordist listens to a monitoring loudspeaker when in a studio, or to a pair of head telephones when on location away from the studio. To determine how the sound is being recorded, the recordist uses a volume indicator which may take a variety of forms. In a sense, the recordist uses his ears to determine what is being recorded and his eyes to determine how it is being recorded.

Head Telephones

Monitoring with head telephones* cannot help but be a compromise with quality. Since monitoring is done by the mixer man, the mere presence of a telephone cord connecting his pair of head telephones to a table, panel, or other point where the current is fed to the telephone, is a physical and psychological handicap which prevents the mixer man from responding very rapidly to the sound he has seen or heard, and which requires some movement of a mixer "pot" or some preparation on his part for the moving of a mixer "pot" or control. Despite this, much dialogue recording in 35-mm entertainment films is done with the mixer man located right on the set where shooting is taking place; under these conditions only head-telephone monitoring is practicable. A number of types of head telephones have been used for the purpose; they vary in size, weight, performance, and in degree of comfort for the wearer. The Western Electric 1002F headset is a very common sight around recording studios because of its sturdiness and its consistency of performance; its high-frequency response is rather poor, however. A Western Electric 714C headset has also been used; its frequency characteristic is quite good and it is small and light, being one of the plug-in-the-ear variety (on the style of hearing aids). Both Western Electric

* Such monitoring is quite misleading in the judgment of sound quality, as a binaural effect is presented to the mixer man that is entirely absent for the ultimate audience.

and RCA have marketed moving-coil headsets of the more conventional variety, using rubber cushions over the earpieces. This type of headset usually has good fidelity, but it is quite uncomfortable to wear particularly when it is warm. Moving-coil headsets are not rugged, being put out of order easily if they are dropped. When so damaged, they usually require expensive repairs.

Loudspeakers

Monitoring with a loudspeaker is more satisfactory, although it does require a good noise-free monitor room that is acoustically good and is acoustically well insulated from the studio and other sources of sound and noise. For best monitoring, it is usually necessary to place the sound-recording machine in a different room from the monitor room, since the mechanical noise made by the sound-recording machine is a serious source of noise—masking the intended signal. It should be unnecessary to mention that the loudspeaker should be so placed that there is no obstruction between its mouth and the ears of the mixer man.

A monitoring amplifier is needed to raise the level from that at the recording bus* to that required for the loudspeaker. The monitoring amplifier should be excellent in its response-frequency characteristic, it should have a high signal-to-noise ratio, and should have low distortion at the operating level. It should also be flat within 1 db from 50 to 15,000 cps and show not more than 1/2 to 1% total harmonic distortion at its operating level. Such amplifiers are fairly widely available at prices ranging upward from about $100 (including tubes).

Loudspeaker performance varies very widely. Unfortunately, the art of measurement of loudspeaker performance has not advanced to the point where the performance of a loudspeaker can be exactly and accurately described by characteristic curves. In the case of the more expensive divided-range loudspeakers that use metallic or plastic diaphragms for the upper portion of the frequency range, the performance variation from one unit to another is fortunately small. In the case of the cheaper single-diaphragm loudspeakers, the performance variation

* The term "recording bus" is used to indicate a point in the electrical circuits of a recording equipment where a number of devices are connected for simultaneous operation. A point often used is the output of the main amplifier; from the bus fed by the main amplifier are connected such units as the input to the power amplifier for the sound-recording machine, the power amplifier for the monitor loudspeaker, the volume indicator, and power amplifiers for energizing auxiliary recording apparatus such as wire or tape magnetic recorders for direct playback, etc.

from one unit to another is very large and the high-frequency output quite small and inconsistent, varying to an important degree with variations in the relative humidity of the atmosphere. Since good performance and consistent performance must be demanded from a monitor loudspeaker, and since the judgment of the sound quality being recorded is to be trustworthy, the best loudspeaker available should be used. Performance should be good and consistent over the full range of the monitor amplifier. Unless this is so, sounds may be transmitted to the recording light modulator for recording that may not be heard in the monitor loudspeaker, causing the loudspeaker to fail in one of its major purposes —that of permitting a critical evaluation of the sound being recorded.

The loudspeaker should have good transient response as determined by a square wave test. It should have uniform angular distribution within an angle of not less than 30 degrees on either side of the loudspeaker axis; this uniform angular distribution should be maintained not only in the range to 5000 cps, but also in the remainder of the range.

To accomplish all of these objectives in a loudspeaker of reasonable size and cost usually requires a divided-range type of loudspeaker; this type of loudspeaker is the only one that is capable of meeting such requirements at the present time. A number of manufacturers are supplying loudspeakers which meet these general requirements; as in the case of any other sort of manufacture, there are individual differences noted among different types. Fortunately, manufacturing control is quite good and the performance differences between loudspeakers of the same type are accordingly quite small. Manufacturers make both the loudspeaker mechanisms and the enclosures in which such mechanisms are mounted. In general, the enclosures are of two types, one called a Utility, which is primarily functional, and the second called a DeLuxe (or some similar name), which is ornamental as well as functional. Prices begin at a little over $80 for a mechanism; they begin at a little over $30 for an enclosure. It is usually good practice to buy the enclosure from the same manufacturer as the mechanism, so that mounting difficulties will not be experienced.

One of the better "buys" of this kind is in the lower end of the price range—the Jensen H-510. As in other products, price is not always a reliable index of quality. It is not practicable at this time to recommend any loudspeaker unequivocally, since there may be manufacturing changes contemplated for the near future. It can safely be said, however, that the performance of any one of the following loudspeakers

can be relied upon for effective day-to-day monitoring at relatively low cost.

All speakers are of the divided-range type; the first three are competitive coaxial types; the last an excellent two-way type. The low range (below the electrical filter crossover frequency that is between 1200 cps and 2000 cps—depending upon the design) is provided by a cone-type loudspeaker enclosed in a ported* bass-reflex cabinet, and the high range (above the filter crossover frequency) is provided by a short straight-axis horn whose axis is coaxial with the low-frequency cone. Since there is very keen competition among loudspeaker manufacturers in trying to provide really superior performance at the lowest possible price consistent with rugged yet low-cost design, these loudspeakers

TABLE XIX

Good Loudspeakers

Manufacturer	15-inch mechanism		Utility cabinet		De luxe cabinet	
	Type No.	Price[a]	Type No.	Price[a]	Type No.	Price[a]
Jensen	H-510	$ 79.38	B-151	$34.47	D-151	$ 50.64
Altec-Lansing	604B	$143.00	Util	$46.50	DeLuxe	$135.00
Stephens	409	$117.60	52U	$35.28	52D	$105.64
Western Electric	757A (two-way)		About $300 complete			

[a] Current prices

represent excellent values. A number of compromise types have already appeared on the market; from a design standpoint they may be said to be variants of the general idea of two diaphragms in one—the larger is coupled to the smaller by a compliance. As electrical dividing crossover networks are costly, manufacturers have used this mechanical means to reduce the manufacturing cost. Altec-Lansing, RCA, Stephens, and others have manufactured such loudspeakers. Their performance up to the present has been inferior to the recommended loudspeakers and they cannot be recommended for really high-quality monitoring without some qualifications.

* A ported bass-reflex cabinet is an enclosure for a loudspeaker mechanism that has a hole or port so located on the front of the cabinet near the speaker opening that the back wave produced by the rear side of the large loudspeaker diaphragm tends to reinforce the wave produced by the front side, thereby extending the frequency range of the loudspeaker approximately an octave at the low end of the frequency range.

A small single-diaphragm type of loudspeaker worthy of special mention is the Western Electric 755A which has a market price of about $30.00. The performance of this loudspeaker is surprisingly good when used in a small enclosure of only 1 1/2 to 2 cubic feet and it can be recommended where space is at such a premium that bass performance sacrifice can be made. It may well be used as a standard by which the performance of "more fancy" types can be compared.

Visual Monitoring

A variety of arrangements is available for the visual monitoring of speech and program waves; each has its advantages and disadvantages. Each design is based upon certain design considerations; an important consideration is that the ear and the eye are expected to be coordinated during the monitoring process.

Most sound to be recorded on 16-mm film consists primarily of transients, with steady-state tones occurring less frequently. In speech, for example, many important transients die away before the eye can react to their presence. If all the transients are recorded as they might be with a continuous-level recorder, it would be almost impossible for the average eye to encompass and to appreciate the waveform detail at the rate at which the sound is to be recorded. For this reason all designs of visual monitoring systems represent a compromise between opposing factors; in many cases the factors are not explained.

In general, the visual monitor is used to establish the average level of the sound envelope being controlled; the ear establishes the conditions at which the high-speed or transient sounds are to be controlled. Many visual monitoring indicators integrate over a period of time somewhat greater than the average reaction time of the ordinary human being; one example is the electrical volume indicator (VU) meter commonly used in broadcasting. Other forms integrate in other ways; the over-all result is a visual representation that conveys a quick yet detailed impression of the nature of the waves being recorded.

A good monitoring volume indicator* should have the following among its attributes:

(*1*) Ease of reading with a minimum of eye fatigue. This usually means that the movement of the indicator needle, light image, etc., should not be too fast.

(*2*) The movement should be slightly less than critically damped; this is especially true of the indicating pointer of a meter.

* Electrical instruments should conform to ASA Standard C39.1—1949.

Some of the more common visual monitoring arrangements are:

(*1*) A standard electrical Volume Unit meter.

(*2*) A cathode-ray oscilloscope.

(*3*) A moving light beam falling upon a screen or ground glass; this light beam is usually derived from the optical system of the recording machine itself. (Oftentimes, it is the chromatic portion of the light beam that is not used for film exposure; or it may be an auxiliary light modulator arrangement used for monitoring purposes only.)

(*4*) A line of gas-tube "trigger" lamps, each of which lights at a different voltage; the length of the lighted line indicates the volume level.

The standard VU meter is described in ASA C16.5 "Volume Measurement of Electrical Speech and Program Waves." This instrument reads 99% of final deflection in 0.3 second. Being slightly less than critically

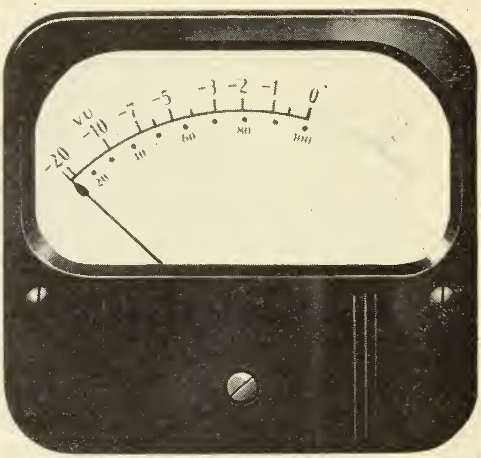


Fig. 72. American Standard electrical volume level indicator (Weston Model 862 Type 30) "A" Scale. *Deflection time:* 99% of its normal OVU in 0.3 sec. ±10%. *Pointer overswing:* 1 to 1.5%. *Distortion introduced due to circuit loading:* Not over 0.3% on a terminated 600 ohms circuit (under worst conditions). *Frequency error:* Less than 0.2 db up to 10 kcps at OVU. *Temperature error:* Negligible at room temperature; less than 0.2 db from 50 to 100 F at OVU. *Scales:* Type A—with upper figures VU emphasized and percent figures small; Type B—with upper percent figures emphasized and VU figures small. *Reference zero:* 72% of scale length. *Calibration voltage:* OVU (100% scale marking) is indicated when 1.225-v. RMS sine-wave is applied to the instrument in series with 3600 ohms resistance; the instrument resistance including the external resistor is 7500 ohms. This calibrating voltage represents +4db above a reference level of 1 milliwatt in 600 ohms. A standard attenuator is required with the instrument for reading different program levels; a typical attenuator is shown schematically in Fig. 72A.

damped, the needle is not "jittery" as with critically damped or slightly overdamped meters. Figure 72 is an illustration of the instrument and its scale. The sensitivity does not depart from its 1000-cps value by more than 0.2 db between 35 and 10,000 cps, nor more than 0.5 db between 25 and 16,000 cps. As commercially manufactured by Weston Electrical Instrument Corp. and others, it is a 4-inch instrument with large readable figures on its scale and a plainly visible pointer. To reduce eyestrain, it can be furnished with internally mounted lamps for scale illumination. In accordance with the ASA specification, two types of scale are available. These are identical except that in one instance the large figures are percentage figures and the small figures are VU figures; in the other, the opposite arrangement is used. The standard instrument is designed for circuits of 600-ohms characteristic impedance. One of the greatest virtues of this instrument is that it is in very wide use, and because of its consistency in indication even over extended periods of time, different persons using the instrument to read indications on the same program waves will arrive at substantially the same readings. This is a feature that is not enjoyed by any other instrument in current use. Figure 72A is the schematic of its attenuator.

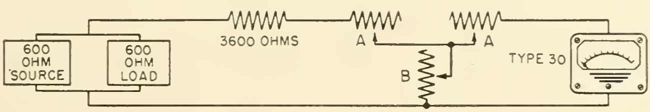


Fig. 72A. Electrical schematic for attenuator for Weston VU meter. A typical attenuator designed for the VU meter of Figure 72 is the Daven TA-1000-2. This is a variable "Tee" pad attenuator with a built-in 3600 ohms series resistor. This attenuator has a low level limit of 1 milliwatt; steps from +4VU upward in 2 VU steps up to a maximum of +40VU are provided. This attenuator also provides an off position at the extreme clockwise detent stop of the control knob. The following table shows the resistance value for each arm. As indicated in the schematic, the 3600 ohms resistor is not included in the table of values. (Each arm A has the value shown in the table.)

Level VU	Arm A, ohms	Arm B, ohms	Level VU	Arm A, ohms	Arm B, ohms	Level VU	Arm A, ohms	Arm B, ohms
4	0.	Open	18	2603.	1621.	32	3601.	311.0
6	447.1	16788.	20	2833.	1268.	34	3661.	246.9
8	882.5	8177.	22	3028.	997.8	36	3708.	196.1
10	1296.	5221.	24	3191.	787.8	38	3747.	155.7
12	1679.	3690.	26	3326.	623.5	40	3778.	123.7
14	2026.	2741.	28	3437.	494.1			
16	2334.	2091.	30	3528.	391.9			

There has been no standardization of any of the other three forms of visual volume indicator; accordingly, there will be greater differences in interpretation for different kinds of program waves as well as greater differences among different observers for the same program waves. This variability in interpretation is a serious handicap, since a volume indicator must be used at every point in a recording system at which sound level must be controlled. Despite the shortcomings of volume indicators, any one method will in all likelihood prove satisfactory if the same kind of sound is recorded day after day by the same operator and with the same equipment. If the character of the program waves is changed, or if the characteristics of the recording channel are changed in comparison with the way they ordinarily look and sound to the mixer man, it is necessary for him to reorient himself to the altered conditions. For this reason, once a monitor loudspeaker and a volume indicator have been installed, they should not be changed in any way without an adequate reason.

Because of the large element of quick judgment and guesswork that is invariably a part of the sound-recording process, it is not reasonable to expect an operator who has been recording only one form of sound (*e.g.,* dialogue) to record an unfamiliar type of sound (*e.g.,* a ping-pong match) without making test recordings—regardless of the equipment at his disposal. Each type of visual monitor is better suited to the indication of one specific kind of program wave than to any other. As the operating characteristics of all different types are different, and there is substantial difference between presumably similar indicators of the same type due to the lack of standardization, it is no surprise to learn that if all were connected to the same channel and adjusted to give like indications for dialogue, there will be as many different indications as there are instruments when the sound of the ping-pong ball is transmitted. Fortunately, equipment operators are not called upon frequently to record unfamiliar sounds.

Auxiliary Recording Apparatus

With photographic sound-film recording equipment it is impossible to playback the sound immediately after recording, since the films must first be developed. For production reasons it is not unusual that some form of direct playback is needed immediately after a recording to determine whether or not lines have been "flubbed" (improperly read or spoken) or if other sounds have been produced properly. To do this re-

quires some form of recording machine other than the sound-film recording machine.

A variety of machines suitable for this purpose is available at a wide range of prices. The machine to be used should be synchronous in its operation with the film-recording machine; in this way, the record produced by the auxiliary machine, if of sufficiently high quality, may be used as a "protection record," a record from which a re-recording may be made in the event that the sound-film original is unsatisfactory because of improper exposure, or other similar causes. If a synchronous high-quality record is desired, so-called acetate disks are suitable; suitable machines are made by Presto Recording Corp. of New York and by Fairchild Camera and Instrument Corp. of Jamaica, Long Island, New York. The price of such equipment is around $1000. Although only a small quantity of magnetic recording equipment is available commercially that is exactly synchronous, it is probable that such recording equipment of the sprocket-hole perforated coated-tape type will soon be manufactured in larger quantity and variety. Sufficient strides have been made with oxide-coated tapes to indicate that there need be no great concern about the fidelity available at equal or greater film speeds; the particular quality level required can be met as desired. It should be noted that most sound-recording equipment available is of the non-synchronous type; most commonly available disk recorders, for example, are friction driven between the motor shaft and the rim of the turntable. The rubber, or other soft material used, permits appreciable slip; this is the price paid for the relatively good yet simple and cheap flutter-attenuating drive arrangement.

Control Adjuncts and Auxiliary Apparatus

If film recording is to prove satisfactory, it must be accomplished with microscopic accuracy. Thus, when a measurement of any sort is to be made, it must be made with consistently performing instruments of the required accuracy. This general observation applies to any instrument used—regardless of whether it be electrical, optical, mechanical, or other. One type of instrument to which it is especially applicable is the lamp-current ammeter used for the measurement of exposure lamp current. Most instruments supplied with most recording equipment are entirely too small and have a scale too short to be either accurate or convenient for the operator; this applies especially to the otherwise excellent 3-inch instruments that are so widely used.

Generally speaking, ammeters are guaranteed by their manufacturers to have an accuracy of a specified percentage of full-scale reading at any point of the instrument scale. The usual value for such instruments as the Weston 3-inch types is 2%. Despite their excellence, these instruments do not provide the requisite control—not because the instrument is inaccurate, but because it is improperly applied. The instrument scale is short, its figures small, its divisions light (because they must be narrow), and it has no knife-edge pointer and mirror scale to minimize parallax error. The instrument must be read in a bright light at a short distance and with no shift of the observer's head position between one reading and the next. In the commercial recording of 16-mm sound films, it is almost impossible to meet these requirements with a 3-inch instrument. The fundamental solution is the use of an adequate instrument with suitable viewing conditions.

The very widely-used 3-inch instrument is difficult to read; it is selected because its price is low (about $6.00) and because it is rugged and reliable. Such attributes, although praiseworthy, are not sufficient to justify what amounts to faulty engineering judgment in instrument selection.

Broadly speaking, the usefulness of an ammeter for measuring lamp current depends upon the accuracy of the meter movement and the reproducibility of its indications, and also upon the ability of the user to read the indications on the scale of the instrument. All these factors are taken into account when an instrument manufacturer specifies an accuracy rating for an instrument. Such ratings are customarily expressed in terms of the percent of full scale reading at any point on the instrument scale. The absolute error, therefore, is a minimum at full scale reading, and increases relative to the current measured at lower values. It is an accepted empirical rule that ammeters are customarily operated at about 80% of full scale reading; for an instrument that is expected to read 2 amperes, the full scale reading of the chosen instrument should be about 2.5 amperes.

The accuracy of the meter movement and the reproducibility of its indications are a matter of instrument design and of manufactured quality. Just as in other manufactured products, there are differences in the quality level among the presumably equivalent products of different manufacturers. It is informative to connect a dozen ammeters

of the same make and model number in series, and compare their indications. It is also informative to connect in series a dozen ammeters of presumably equivalent types. There is but one international ampere, and all instruments are presumed to refer to it within their rating guarantees.

Fig. 73. Weston model 273 specification 195 ammeter for measuring exposure lamp current of Maurer sound recording machine. The instrument shown is the minimum length linear-scale instrument adequate for a Maurer sound recording machine using a 2-ampere lamp. Its specifications are: *Make:* Weston. *Type:* Model 273 specification 195. *Range:* 0 to 2.50 amps. *Scale length:* 7.3 inches. *Number of scale divisions:* 125. *Smallest scale division:* 0.02 amp. *Voltage drop:* 100 millivolts (either self-contained or external shunt supplied; specify which). *Pointer:* Combination knife-edge and bead-head. The external shunt is usually preferred as it may be installed inside the Maurer amplifier case in series with the 3-inch ammeter already there. The shunt may be mounted so that only the meter shunt leads (furnished with the shunt) emerge from the case of the Maurer amplifier for connection to the externally-mounted instrument.

The ability of the user to read the scale depends upon the scale length, its design, and the viewing distance. Designs are of two major types: (*1*) with a knife-edge and a mirror-backed scale (to limit parallax error in viewing) that is intended for close and careful viewing and (*2*) a bead-head pointer intended for more distant and less precise viewing. The instrument shown (Fig. 73) has both features, the bead-head being lo-

cated below the knife-edge portion to limit pointer bending resulting from the sudden forces of meter overload. In practice the operator must be close to the instrument and directly view the scale perpendicularly when setting the lamp current; this is necessary to cause the image of the knife-edge appearing in the mirror to coincide accurately with the knife-edge itself. For momentary checking of the lamp current from time to time while recording is in progress, the operator glances at the meter, observing the location of the pointer by noting quickly the bead-head portion. He subconciously compares the new observation with the prior observations to determine whether any change in current has taken place.

It is recommended that the density of the original sound track be controllable within ± 0.1. With the recommended instrument, it is possible to estimate current within one-half scale division, or 0.01 ampere. Since the smallest scale division (0.02) represents a density change of about 0.1 under average commercial processing conditions, the accuracy of the instrument is properly related to the operating requirements. Under such circumstances, the recording machine operator can feel confident that film exposure is properly controlled, and that gross exposure deviations are not due to an inadequate exposure lamp current ammeter. Should such deviations occur, the accuracy of exposure lamp current control is sufficient to permit the source or sources to be tracked down methodically.

For most 16-mm sound recording, 2% accuracy of lamp-current control as limited by the ammeter is marginal; better control is required and a reproducibility in the order of 1% would seem to be a more suitable choice. Such control can be obtained ordinarily with the Weston 7-inch instruments shown. Internal instrument illumination to provide adequate light for viewing the instrument scale is also quite desirable; good instrument manufacturers can advise on the scale color and on the illumination level required for optimal viewing at the viewing distance specified. Although the rated accuracy of the 7-inch instrument shown is only 1%, performance of the instrument will be satisfactory because the rated instrument accuracy is realized in practice, and because the reproducibility of the readings of the 7-inch instrument is appreciably higher than that of the 3-inch instrument because of the manner in which the instrument is used. It is self-evident that such instruments should be calibrated at regular intervals if the instruments are to be

relied upon for controlling exposure. As an operating procedure it may be advantageous to use two lamp-current ammeters, one located at the mixer desk and one at the sound-recording machine. Such an arrangement makes it possible for the mixer man and the recording-machine operator to check one another.

Progressive instrument manufacturers such as the Weston Electrical Instrument Corp. have recognized for some time the need of increasing the useful scale length of their instruments, and now supply on special order the suppressed-zero feature in many catalog instruments. Suppressed-zero instruments are available in two designs; mechanical suppression and electrical suppression. Both instruments are currently available in a maximum of about 60% suppression for d.-c. instruments; in the instrument shown, the lowest scale reading would be 1.50 amperes rather than 0 ampere, and the full scale reading would remain the same —2.50 amperes. The effective scale length would be more than doubled for such an instrument as it is not used below 1.50 amperes.

Mechanical suppression is accomplished in the instrument shown by the use of a special design of armature restraining spring. Electrical suppression is accomplished through the use of two separate current coils in the armature suspension saddle instead of the customary single coil. Mechanically suppressed zero instruments* are cheaper; the electrically suppressed type retains its calibration better over long periods of time.

Two good densitometers, one of the Eastman type and the other of the Western Electric type, are desirable. The former is needed for the less accurate production measurement of densities of the order of 1.0, and the latter is needed especially for the measurement of fog and of other densities of the order of one-tenth of the former and for more accurate high-density measurements. It must be remembered that film laboratories customarily make a minimum of density readings of the films they turn out, and rarely make accurate readings of fog. Thus, the equipment operator should make readings on all his film—some readings to check the laboratory, and other readings for control purposes and for process improvement purposes. It will be necessary for the equipment operator to make his own readings and interpret them rather than attempt to "pass the buck" for this routine examination and responsibility to someone else, if the quality of the recorded sound is to be maintained, and if the data necessary to determine just where and how much improvement should be made is to be collected.

If good control of sound quality is to be achieved, da a concerning

* Such instruments become inaccurate with lack of use.

process variations from day to day must be accumulated—a laborious and time-consuming process. What is invariably bound to happen in the absence of such data is a downhill trend in recorded sound quality that is so gradual that it slips by the inspection of the original and is detected in aggravated form in an unsatisfactory release print.

Routine tests should be made at the end of every roll of film recorded. Further routine tests should be made periodically (*e.g.*, weekly) to check the change in characteristics of the equipment and processing with time. Such tests need not consume appreciable quantities of film; informative tests can be run with little more than the amount of film ordinarily wasted as short ends. Transmission, flutter, and cross-modulation tests should be made as frequently as possible not only to determine average conditions, but also to determine the magnitude and the causes of day-to-day variations.

The Society of Motion Picture Engineers sells a series of excellent test films that may be used for checking equipment performance. The multi-frequency test reel, for example, may be used in a re-recording film phonograph to check the over-all characteristics of the re-recording channel. It may be sent to the laboratory for 16-mm prints; a print may be made on either black and white or color film. Differences between re-recording and photographic printing can be quickly estimated by comparing the films produced. Although the test conditions are not exactly equivalent to commercial operating conditions, the results will still be sufficiently close to indicate the order of the similarity or difference. Much valuable operating data can be gathered quickly by such simple tests. Practical production problems will indicate numerous other uses for these most valuable test films.

Data concerning availability, methods of test, and suggestions for further uses can be obtained from the Engineering Secretary, Society of Motion Picture Engineers, 342 Madison Ave., New York, N. Y.

Physical Placement of Equipment in Recording

It must be remembered that the gain of an amplifying system used for recording is quite high; 100 db is a common value between the microphone input and the output feeding the monitor. Because of the high gain the following conditions should be met:

(*1*) When no intended sound originates within the studio, no sound other than system hiss should be heard when the monitor gain is advanced above normal. It must be kept in mind that the original record shall be as free of noise as possible because

every succeeding step of processing, printing, and handling increases the noise level. To make a simple test, merely increase the monitor gain at least 20 db above normal operating gain and listen critically. If any extraneous noise or sound is heard, take steps to eliminate it. Listen particularly for the noise of machines (such as the scoring projector or the camera), extraneous conversation carried on in distant rooms, elevator noise, etc.

(*2*) The acoustic insulation between the studio and the monitor room should be high if headphones are used for monitoring, and much higher if a loudspeaker is used for monitoring. The acoustic isolation between the monitor-produced sound and the microphone is good when headphones of the hearing-aid type such as Western Electric 714C are used, since very little sound escapes into the monitor room from the headphones, and the insulation between the monitor room and the microphone is quite large. On the other hand, acoustic isolation between the monitor-produced sound and the microphone is comparatively very poor when a loudspeaker is used for monitoring, since the sound level produced by the monitor speaker is very much higher than that of the monitoring headphones, and the path between the mouth of the loudspeaker and the ears of the mixer is neither enclosed nor restricted. The sound from the loudspeaker impinging upon the multiple glass panel between the mixer room and the studio provides a low-impedance ''feedback howl'' path, with the glass panel as the primary attenuator in its path. To make the attenuation a maximum, the attenuation per unit area is made a maximum by using two or even three pieces of thick plate glass ''floated'' acoustically and with dead air spaces between them, and with the area of the panel a minimum. Generally speaking, sound-insulating walls provide appreciably more insulation for a certain dollar cost of construction than glass observation panels.

(*3*) The acoustic insulation between the mixer room and other sources of noise such as the noise produced in the machinery room by the recording machines, film phonographs, scoring projectors, and the like should be very high. Here again the isolation is quite high when headphones are used, since the noise is excluded from the ears of the mixer man by the headphones themselves. With complete silence in the monitor room, it should not be possible for the keenest pair of ears to tell whether any machinery is running in an adjacent machinery room, or whether any performance is taking place in the studio proper.

It is evident from the foregoing that there are two primary classifications: one for monitoring with headphones, and another for monitoring with a loudspeaker. The former is quite advantageous from the standpoint of noise because less expensive studio wall construction is required. It is possible with headphones monitoring to have the mixer man right on the set or stage and to pipe* the signals to a more remote point where the recording machine is located. Unfortunately, most headphones have a decidedly poor response-frequency characteristic, are uncomfortable to wear, and interfere with the physical freedom of the mixer man. When recording is in progress, freedom to move arms unhampered together with utter convenience of all operating controls and instruments make for a better sound track.

Headphones are also misleading in sound quality because the masking effects of extraneous noise heard in the headphones are much less

* Colloquial expression meaning ''to transmit.''

perceptible than the same noise heard in a loudspeaker (such as the loudspeaker of the sound projector). This leads to an underestimation of the subjective importance of the extraneous noise. Generally speaking, the recording of speech is quite satisfactory with headphones monitoring, but unsatisfactory for the recording of music—especially of the symphonic type. Low-frequency rumbles and high-frequency noises are especially annoying since they are not readily heard due to the poor response of most headphones to both low and high frequencies; such noises may therefore be recorded unwittingly.

In general, the conventional wall arrangement for a small studio is in the shape of a letter "T" (Fig. 74), separating the recording studio

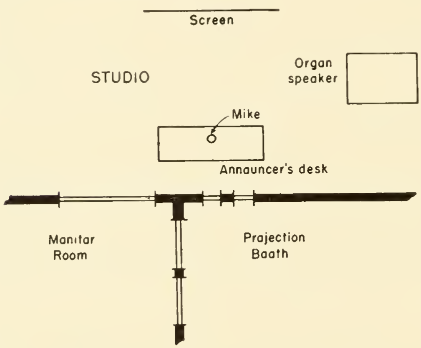


Fig. 74. Generalized "T" shape arrangement of studio, monitor room, and machinery room in sound recording.

proper, the mixer room (often called the control or recording room), and the machinery room (often called the equipment room). In the mixer room are found the mixer controls and switches, including audio patch panels and equalizers, visual and aural sound monitors and volume indicators, a footage or time-measuring indicator (usually a small synchronous motor driving a Veeder counter or a sweep hand of a clock-like arrangement), and form of intercommunication system. In the machinery room are found all the noisier rotating machinery and their switches and controls, such as the recording machine (film, disk, etc.), the film phonographs, the disk turntables (both 78 rpm and 33 1/3 rpm), the scoring projector, and an "intercom." In the studio proper will be found the microphones—and the inevitable intercom. The amplifier equipment proper is often, though not necessarily, located in the mixer room. If preamplifiers can be located apart from the remainder of the equipment, it may be desirable to locate them in a different, very quiet room in order to avoid microphonic response of their electron

tubes to sounds such as those produced by the monitor loudspeaker, by the noise of rotating machinery, by the vibration of such machinery transmitted to the electron tubes, or by building or other vibration similarly transmitted. As has been pointed out, multiple glass panels (not less than two thicknesses of plate glass) between adjacent rooms should be kept as small as possible in area to reduce the total energy of sound transmitted from one room to another. As the effectiveness of the acoustic isolation actually obtained depends upon suitably isolating the panels acoustically from their supports, construction design is very important. Basic information concerning such design may be obtained from manufacturers of acoustic materials such as Johns-Manville. In the interest of providing the most effective use of the materials manufactured, many of these firms provide advisory services for materials users.

In general, when cost is to be kept to a minimum, monitoring with headphones is most practicable—especially if only a commentary voice is to be recorded. However, loudspeaker monitoring is definitely preferred for re-recording. When the purpose of the re-recording is to "mix" sound tracks prior to the making of a re-recorded sound negative or sound positive for release printing, the mixer room where original recording is accomplished is quite satisfactory and convenient. When the purpose of the re-recording is to prepare a sound negative or sound positive for release printing, the re-recording console and its controls are best located at the rear of a small simulated auditorium. To improve the illusion for the mixer man, a screen of 4 to 6 feet wide may be set up at the forward end. The mixer man should be located at a distance of 5 w from the screen;* this position should assure that the listener at the rear of an auditorium has been considered when the sound was re-recorded. To check the probable effectiveness of the re-recording qualitatively, a loudspeaker of the type ordinarily used with the commercial sound projector on which the films are to be run can be substituted for the monitor loudspeaker by switching back and forth during a rehearsal preceding the "take." (This comparison by switching is referred to as an A-B test.) If the sound heard from either loudspeaker is not crisp and bright, and free from harshness, distortion, and noticeable noise, it is likely that the re-recording will not be satisfactory. One or two preliminary test re-recordings will aid in establishing the mental reference required for production re-recording; the release print

* w represents the width of the screen. Perspective of viewing is fixed when the distance from the screen is specified in terms of screen widths. (See chapter XIII).

prepared from the test should be compared directly with the monitor sound of the re-recording channel to indicate the losses encountered in production.

Technique of Sound Recording

When an event occurs that we wish to record, there are several conditions as yet unaccounted for that require consideration. The effectiveness of the compromises decided upon as a result of these conditions may ''make or break'' the final result despite the very best equipment, processing, film, and technical facilities.

One factor is that all 16-mm commercial sound recording is monaural or ''single-eared'' while all human hearing is binaural or ''two-eared.'' The brain has the faculty of discriminating against noises that it chooses to disregard, and concentrating on sounds that it chooses to hear; this faculty is quite apart from the purely physical and physiological factors that are a result of the construction of the ears and their location in the head. Unconsciously, we turn our heads to discriminate against noise that originates in a direction different from that of the sound we choose to hear.

Conventional recording systems, being single-channel arrangements, do not provide the noise discrimination and the directional discrimination that is common to binaural hearing; in effect they act somewhat in the manner of one useful ear and one plugged-up ear. With such systems, therefore, the twisting of the head does not provide the accustomed corrective effect bcause the extraneous noise originates (as far as the listener is concerned) from the identical point in space—the loudspeaker—as that of the sound of interest.

To correct this effect to some extent, it is essential to reduce extraneous sounds to a minimum. Directional microphones are used to limit the noise introduced into the recording channel. To limit the effect of the noise introduced by the remainder of the process, noise reduction, volume compression, etc. are used. Efforts are constantly being made to improve the signal-to-noise ratio of recording systems, since a particular level of noise in a conventional 16-mm reproducing system is much more disconcerting and attention-diverting than the same amount of noise experienced in natural listening.

Usually, a directional microphone should be used at a relatively short distance from the sound source. In this manner the greater portion of the sound reaching the microphone is received directly from the source with no reflection at all. The lesser and intentionally small portion of

the sound is randomly reflected from the boundaries or walls of the pickup space or set, and from objects within the space. To reduce the ratio of reflected sound to direct sound still further, sets are made less reverberant than normal by the use of considerable quantities of strategically placed sound-absorbing material on the walls and other flat surfaces. Unfortunately, 16-mm projectors are often run in highly reverberant rooms; recorded reverberation must be kept to a minimum on the film if the overall result is to be intelligible under such unsatisfactory reproducing conditions, as the reverberation (echo) effect of projection is added to that of recording.

Another important factor is the degree of mobility of the sound source with respect to the microphone. Since pressure-type microphones are nondirectional at low frequencies and quite directional at high frequencies, the "wiggling about" of a speaker's head translates itself into objectionable changes in voice quality due to the changes in the amount of high frequencies arriving at the microphone. If more uniformly directional microphones—such as the cardioid or the velocity types—are used, the effect of "head wiggling" is less noticeable. Such microphone types do not discriminate as seriously with respect to frequency; accordingly, the primary effect of "head wiggling" is to produce small changes in volume rather than serious changes in quality.

The problem of quality variation due to source mobility is far more serious when it is necessary for actors to move about a set to provide the desired pictorial action. Although sound pickup is not simple under these conditions, the final result does not suffer if adequate equipment and personnel are used. Most 16-mm films cannot afford the high costs that such production entails; to accomplish such recording requires the duplication of the complicated and expensive equipment and numerous personnel used for a Hollywood production.

Since many 16-mm films are recorded with a single off-stage voice, the problem of mobility of the sound source does not arise. It is usually sufficient to record within a relatively small space (the space may be as small as 600 cubic feet), making certain by attentive listening to the monitor speaker that satisfactory sound pickup is being obtained. It is especially important in the case of a small space that the length-to-width-to-height relationships be of the order of 1 : 1.25 : 1.5 or multiples thereof; this dimensional relationship among the three axes of the room is necessary to provide "randomness" to sound reflected from the room surfaces. Further data in condensed form may be obtained from the excel-

lent Engineering Handbook issued by International Telephone and Telegraph Company in the section dealing with room acoustics.

One of the very common causes of unsatisfactory sound pickup is aptly illustrated by undesirable short-path reflections that result when sound is ''bounced off'' the top of an uncovered wooden desk when a commentator reads from text that rests on the desk, and the microphone is suspended directly above it. An alert mixer man with good hearing, listening to the sound through a high-quality monitoring loudspeaker system can instantly recognize this condition and quickly instruct the commentator to correct the sound defect. The table top will be covered and reflection from its top ''broken up'' by placing various items on it; the microphone placement will be altered so that the primary contribution to the sound at the microphone will be made by the direct sound of the announcer's voice—with a minimum contribution by the sound directly reflected from the nearby top of the desk. All this is done before the mixer man permits a recording to be made; it is essential that he be satisfied with the sound quality before a ''take'' is actually made. Generally speaking, an attempt to correct a defective sound track in rerecording is foredoomed to failure; it is far simpler and more satisfactory to record the sound track properly when the original recording is under way.

A third contributing factor related to the differences between monaural and binaural listening as they affect recording quality is the environment of the recording microphone. Sound travels from its origin or origins to the microphone. Even though it may not be impeded by objects between the sound source and the microphone, still, the dimensional and surface characteristics of the surfaces of the recording space, such as the walls, the ceiling, floor, etc., that reflect sound, and their distances relative to the sound origin and to the microphone, play an important part in determining not only the reverberation time (which depends upon the distances) but also the relative intensity of the reflected sound with respect to the directly received sound. The distance relations of the reflecting surfaces determine the reverberation time and the ''randomness'' of the reflection. Even the ear itself plays an important and often unrecognized part; if two sounds of equal pressure are heard that have different ratios of reflected to direct sound, the sound with the larger reflection component will seem appreciably louder subjectively than the sound with the smaller reflection component.

At present, the day-to-day variations in sound quality are so large due

to processing and other variations such as projection acoustics, that the introduction of appreciable intentional reverberation is usually undesirable because of the very limited useful dynamic volume range found in 16-mm prints as customarily projected. Too often the introduction of reverberation also introduces large unexpected noise components that will further seriously limit an already small signal-to-noise ratio that is little better than marginal.

Much could be written about the technique of sound pickup for 16-mm recording. None would be of any value whatever if the "man at the controls" does not have good hearing provided by "balanced" ears, a good memory, and intelligence, together with the habit of being meticulously careful in everything that he does. Sound recording is not just a mechanical process; the result depends upon how accurately "the man at the controls" has weighed his problem. If the result as projected on the reference projector in the reference auditorium is good, he has done it well. The difference between what is expected and what actually happens is a measure of his judgment, and of the control of the process of making a release print from a recording of an original event.

As in any other field of scientific activity, the man will keep accurate records of everything that he records and does, and he will consult his records and recordings regularly to evaluate for himself whether the present recording shows steady improvement over his earlier work, and where and how to make future recordings even better than the present ones. At regular intervals he will call in trained associates to listen to samples of recording made for different pictures at different times; broadly speaking, his evaluations should be confirmed by those of his associates. At such times, samples of the best quality recordings made by others should be included in the review; by direct comparison, it is possible to evaluate the sound quality he is providing relative to that of the competitive market. Shortcomings, when detected, should be tracked down and corrected with minimum delay. It is only with such regular review that the sound recordings produced may be used confidently.

Re-recording

Since the optimal use of re-recording can result in such a high level of improvement in quality, attention may justifiably be given to some of its applications.

There are several general requirements for the projection of sound

films in the accomplishment of which re-recording can play a controlling part.

(*1*) During projection there should be no need to ''diddle'' or otherwise alter either the volume control setting or the tone control setting between the beginning of a reel or subject and the end of the reel or subject. Sound quality and sound volume should be just as consistent throughout a release print as the picture is expected to be. Since no ''diddling'' of picture brightness or tone is required, there should be no ''diddling'' of sound volume or ''brightness'' of tone.

(*2*) All portions of the film, whether of speech, music, sound effects, or any combination of them shall be intelligible and pleasing to all in the audience who can satisfactorily view the screen. In this regard it should be remembered that the sound radiated to the sides and to the back row of the theater is usually seriously deficient in high frequencies when the conventional box-type ''portable'' flat-baffle type loudspeaker is used for sound projection. (Most sound projectors are equipped with this inadequate type of loudspeaker because it is the cheapest available.) To compensate somewhat for this defect, it is necessary to equalize even beyond the amount dictated by other considerations.

(*3*) The sound shall be in keeping with the pictorial content of the picture both in quality and in aspect. Should voice quality be disconcerting for some reason, it should be possible to do something about it rather than to permit all audiences to suffer through a carelessly done job. (The 4031B Cinema Engineering Program Equalizer is useful for this purpose.)

(*4*) Should a reasonable increase in sound output above an arbitrary ''normal'' be required to ''override'' increased auditorium noise (for example, due to an increase in the size of the audience during the showing), such change should be possible without a noticeable increase in distortion and noise, or change in sound quality.

(*5*) Release prints should be consistent in quality, noise, and distortion from one print to another of the same subject and should show but minor variations from one subject to another.

These requirements are not easily met. The final result obtained is a compromise that involves the cost to an important degree. Technical factors involved relate to hearing perception, recording technique, laboratory processing and release print manufacture, the recording process itself, and even to psychological factors—such as the attention accorded the film by the audience.

Obviously, the original record should be the best that we know how to turn out. It is even more important that the quality throughout the original recording be consistent; if correction is required, then the same correction can be applied to the complete film rather than a large series of special corrections for different pieces.

When off-stage voice (commentary) is to be recorded, obtaining a good sound record would seem to be quite simple. Unfortunately it is not as easy as it looks; even a trained announcer does not find it easy to speak

with the same voice quality continuously throughout the 11 minutes required for the recording of a single reel. The difficulty with an untrained speaker is accentuated; he may begin a recording session satisfactorily, but is usually incapable of "following through" for the full period. Before the end of a single reel is reached, an appreciable change in delivery (such as tempo, pitch, emphasis, inflection, and even diction and intelligibility) occurs merely because the effort is tiring. The untrained speaker is usually unaware that a change in voice quality is occurring; he does not realize what is happening because his efforts are concentrated upon the mere mechanics of reading and speaking.

With thoroughly professional voicing and recording, it should be possible to shift phrases or sentences from their original positions in a sound track to some other position if dictated by the editorial need of the picture. When the altered film is projected, there should be no noticeable change in sound quality to an average listener who may hear the film. Such sound "cutting" may often prove impractical because of sound blooping difficulties; it will be much easier to record the original properly.

If synchronized dialogue and similar sound is recorded, photographing is done scene by scene. As a total of some 70 to 150 scenes is customary in a typical edited reel of 11 minutes length, each scene averages only 5 to 10 seconds. Since each scene requires a different camera view, it also requires a different location and orientation of the recording microphone. The success of the illusion that the film is a continuous story and a unified whole rather than merely a collection of "bits and pieces," depends upon the uniformity with which the individual scenes have been recorded. Because the quality of each scene is judged individually by the ear of the recordist when the recording is made, a successful sound track of this kind represents a feat of memory quite as much as it represents a trained ear. In any event, the viewing audience expects—and customarily receives—a result that is smooth and free from noticeable quality departures not only from scene to scene but also throughout the complete reel or subject. This result can be accomplished by suitably skilled personnel as a regular day-to-day occurrence when they have the proper facilities at their disposal and when they receive the active cooperation of laboratory, editing, and other production personnel. Any lesser result should be discarded as substandard.

Again it must be pointed out that the quality losses in each transfer step of 16-mm film handling are quite large and vary over an unnecessarily wide range from one lot of release prints to another, and even

from one release print to another within a single lot of release prints. It is evident that the losses which cause these changes must be known if they are to be anticipated and their adverse effects limited. As sound recording men are often the only production men trained to appreciate and understand these variations, it is evident that they must listen to several release prints derived from the same original and compare the prints directly with the original or with the final trial composite print or appropriate sound check print. This should be a routine follow-up matter if any serious attempt to produce consistent sound quality is made. It is well to remember that the mere recording of an original that "sounds good" to an untrained observer in the mixer room is no assurance that release prints derived from the original will have any commercial value. Under certain circumstances the losses of the anticipated procedure may be so great that the result will be unsatisfactory because the original record was made with a frequency range or with a dynamic volume range that was too large. Sound records from which release prints are derived must be "geared" to the release prints they are to produce.

It is impracticable in many cases to expect the original sound record to anticipate satisfactorily all the subsequent process variables and to correct for them. A reasonable requirement is a noise-free and distortion-free sound record—preferably pre-equalized—that may be subsequently re-recorded to provide the optimal characteristics for the pre-print material used in printing the release prints.

It is reasonable to expect that release prints will be made by printing directly from a re-recorded release negative should black-and-white prints be required. It is also reasonable to expect that composite color duplicate prints will be made by printing directly from a re-recorded release direct positive. It is only in this manner that the unknown variables can be kept to a minimum consistent with reasonable cost.

If a relatively large number of transfer steps must be anticipated between the original sound record and the re-recorded release negative or positive, there is cause for concern in meeting the competitive quality requirements because of the magnitude of the film losses. For such special cases it may be necessary to make the original record at a linear speed appreciably greater than the standard 16-mm speed of 36 feet per minute; a 2-to-1 speed ratio would seem to be an appropriate minimum. Generally speaking, if the recording is photographic, it will be better to make such a higher speed record on 16-mm equipment than on

35-mm equipment as the losses of commercially available 35-mm equipment under comparable conditions are greater than 16-mm equipment; further advantage is also obtained from the higher quality of specialized 16-mm film processing. In general, all steps prior to the release negative itself should be processed at the higher film speed if losses are to be kept to a minimum. Possibly high-speed (18 in. per sec.) magnetic tape recording may be the answer of the future for all stages prior to the release sound negative.

Since each particular recording method and transfer process has distortion characteristics that are peculiar to it, the evaluation of distortion comparisons among the various methods in other than a qualitative manner is still difficult. Despite this difficulty, a generalization can be made that holds true in a sufficiently large number of cases: if an original record is made by one recording method (*e.g.*, variable-density), the over-all distortion of a copy will be smaller if the re-recording method is of a different kind (variable-area). (This generalization presumes complementary recording of negative and positive for both variable area and variable density where such recording is applicable.) It has been found empirically that under "average" conditions, distortion produced by using the same recording method several times in succession is more disagreeable aurally than if different methods are used. Apparently there is a "piling up" of similar distortion products that does not occur when different methods are used; the ear is seemingly more tolerant when distortion products are "spread out" over the spectrum than when distortion products occur at the same "spots" in the spectrum. If a high-quality original recording were made on an up-to-date Western Electric variable-density 35-mm channel on DuPont 225 negative, and a good 35-mm print made on DuPont 226 (to be used to provide a re-recorded 16-mm variable-area release negative on EK 5372), less distortion will ordinarily appear on the release print than if the high-quality original recording were made on a modern RCA variable-area 35-mm channel. If the re-recorded release negative were to be of the variable-density type, the reverse might be expected to be true.

At the present time, the losses in 16-mm films and processing are so large that re-recording from 16-mm to 16-mm must be very accurately controlled if "elbow room" for convenient operation is to be provided. Unfortunately, very accurate control cannot usually be accomplished for numerous reasons, and other means must be used to provide the much-needed "elbow room." For the present, such means will imply a better

quality original record with lower noise and lower intermodulation distortion. In photographic recording the avenues are clearly indicated: they may include push-pull recording, variable-density recording using higher film speeds, and possibly, wider sound tracks; these avenues have already been utilized in 35-mm recording. Perforated magnetic tape recorders with tape speeds of 12 to 18 in. per second seem to have distinct possibilities; the tapes (suitable for original records) may be of the 16-mm safety-film-base type perforated with one row of sprocket holes, or they may be of the paper type (similarly perforated), suitable for editing. In any event the result should be quality equal to present original 35-mm motion picture recordings. This quality is necessary in any recording subsequently re-recorded and used as part of the release, or any recording which is used as a playback quality check of original material.

Blooping

Since two strips of film, when spliced together with the customary lap joint, cause a very irritating and rather loud noise as they pass the scanning beam of a sound reproducer, masking or other silencing of the splice is required; such masking or silencing is known as blooping. In general, release negatives and release positives are made in one continuous piece without splices of any sort; the problem of blooping is therefore one of controlling the noise produced when the spliced re-recording print is run through the re-recording film phonograph. Many forms of punches, patches, and paint-outs have been used successfully with 35-mm films, but the use of comparable methods has not been equally successful in 16-mm. Fortunately, blooping is not a problem in many films, since the sound is merely a commentary that has been recorded in one single continuous piece. For the very specialized case of 16-mm films of the synchronized dialogue type where the number of splices in a 400-ft. reel may be as high as 150, the use of such mechanical blooping methods is not very satisfactory in performance and is very time consuming. A suggestion has been made by Lewin in the Journal of the Society of Motion Picture Engineers* that the output of the preamplifier of the re-recording film phonograph may be short circuited or otherwise disconnected during the interval that the splice passes the sound-scanning beam, thereby silencing the splice noise electrically. The method utilizes a microswitch to effect the short circuit; the microswitch is actuated me-

* Lewin, G., "A New Blooping Device." *JSMPE*, 48, Apr. 1947, p. 343.

chanically by permitting the microswitch lever to drop as the film—which has been punched at an appropriate point—passes by. With a film re-recorded in that manner, the noise of passing splices is eliminated just as effectively as if the mixer channel key were automatically turned off during the required interval. It is truly strange to relate that sound re-recording had been a commercial process for some 15 years before the appearance of this fundamental yet utterly simple solution to the problem of sound blooping for re-recording. The long delay in the appearance of this simple technique would appear to suggest very strongly that there are probably many other first-order problems awaiting similarly simple solutions. Such problems and their solutions will appear in the everyday job of providing better sound on prints with a minimum of man-hours of labor and a maximum of effectiveness; every person engaged in or interested in the job of recording, re-recording, processing, printing, projection, and all other operations has an opportunity to recognize a need and to find a solution. The job of improving the performance of equipment can be left to the engineers in the field; their efforts should be directed, however, to improving the performance in the general directions indicated by those engaged in the everyday job of sound-film production—and especially the operating sound engineer.

Selected Bibliography

Begun, S. J., *Magnetic Recording.* Murray Hill, New York, 1949.

Kellogg, E. W., "The ABC of Photographic Sound Recording," *JSMPE, 44,* 151 (March 1945).

Kellogg, E. W., "A Review of the Quest for Constant Speed," *JSMPE, 28,* 337 (April 1937).

Kellogg and Drew, "Filtering Factors of the Magnetic Drive," *JSMPE, 35,* 138 (Aug. 1940).

Albersheim and MacKenzie, "Analysis of Sound-Film Drives," *JSMPE, 37,* 452 (Nov. 1941).

Wente and Muller, "Internally-Damped Rollers," *JSMPE, 37,* 406 (Oct. 1941).

Hopper *et al.*, "A Light-Weight Sound Recording System," *JSMPE, 33,* 449 (Oct. 1939).

Hopper and Moody, "A Simplified Recording Transmission System," *JSMPE, 47,* 132 (Sept. 1946).

Kellogg and Morgan, "Measurement of Speed Fluctuations in Sound Recording and Reproducing Equipment," *J. Acous. Soc. Am., 7,* 271 (April 1936).

Scoville, R. R., "A Portable Flutter-Measuring Instrument," *JSMPE, 25,* 416 (Nov. 1935).

Strock, R. O., "Some Practical Accessories for Motion Picture Recording," *JSMPE, 32,* 189 (Feb. 1939).

Kellogg, E. W., ''A New Recorder for Variable Area Recording,'' *JSMPE, 28,* 653 (Nov. 1930).

Goehner, W. R., ''A New Mirror Light-Modulator,'' *JSMPE, 36,* 488 (May 1941).

Frayne, J. G., ''Noise Reduction Anticipation Circuits,'' *JSMPE, 43,* 313 (Nov. 1944).

Scoville and Bell, ''The Design and Use of Noise Reduction Bias Systems,'' *JSMPE, 38,* 125 (Feb. 1942).

Snow and Soffel, ''Electrical Equipment for the Stereophonic Sound-Film System,'' *JSMPE, 37,* 388 (Oct. 1941).

Hilliard, J. K., ''The Variable-Density Film Recording System Used at MGM Studios,'' *JSMPE, 40,* 148 (Mar. 1943).

Aalberg and Stewart, ''Application of Non-Linear Volume Characteristics to Dialog Recording,'' *JSMPE, 31,* 248 (Sept. 1938).

Drew and Sachtleben, ''Recent Laboratory Studies of Optical Reduction Printing,'' *JSMPE, 41,* 505 (Dec. 1943).

Maurer, J. A., ''The Present Technical Status of 16-Mm Sound Film,'' *JSMPE, 33,* 315 (Sept. 1939).

Miller, W. C., ''Preliminary Report of Academy Research Council Committee on Rerecording Methods for 16-Mm Release of 35-Mm Features,'' *JSMPE, 45,* 135 (Aug. 1945).

Pettus and Sachtleben, ''A New Variable-Area Recorder Optical System,'' *JSMPE, 50,* 14 (Jan. 1948).

Denney, B. H., ''Cathode-Ray-Oscillograph Images of Noise-Reduction Envelopes,'' *JSMPE, 50,* 37 (Jan. 1948).

Thayer, W., ''A Multi-Section Rerecording Equalizer,'' *JSMPE, 45,* 333 (Nov. 1945).

Mueller and Groves, ''Magnetic Recording in the Motion Picture Studio,'' *JSMPE, 52,* 605 (June 1949).

Gunby, O. B., ''Portable Magnetic-Recording System,'' *JSMPE, 52,* 613 (June 1949).

Crane, G. R., ''Studio 16-Mm Re-Recording Machine,'' *JSMPE, 52,* 662 (June 1949).

Singer, K., ''Preselection of Variable-Gain Tubes for Compressors,'' *JSMPE, 52,* 684 (June 1949).

Keith and Pagliarulo, ''Direct-Positive Variable-Density Recording with the Light Valve,'' *JSMPE, 52,* 690 (June 1949).

Singer, K., ''Versatile Noise-Reduction Amplifier,'' *JSMPE, 50,* 562 (June 1948).

Singer, K., ''High-Quality Electronic Mixer,'' *JSMPE, 52,* 676 (June 1949).

Collins, M. E., ''A De Luxe Film Recording Machine,'' *JSMPE, 48,* 148 (Feb. 1947).

Miller, B. F., ''Elimination of Spectral Energy Distortion in Electronic Compressors,'' *JSMPE, 39,* 317 (Nov. 1942).

Rettinger and Singer, ''Factors Governing the Frequency Response of a Variable-Area Film Recording Channel,'' *JSMPE, 47,* 299 (Oct. 1946).

LaGrande *et al.*, ''16-Mm Release Printing Using 35- and 32-Mm Film,'' *JSMPE, 52,* 211 (Feb. 1949).

Livadary and Twining, ''Variable Area Release from Variable Density Original Sound Tracks,'' *JSMPE, 45,* 380 (Nov. 1945).

Kellogg, E. W., ''Ground-Noise Reduction System,'' *JSMPE, 36,* 157 (Feb. 1941).

Kreuzer, B., ''Noise Reduction with Variable Area Recording,'' *JSMPE, 16,* 671 (June 1931).

Hansen and Faulkner, ''Mechanical Reversed-Bias Light Valve Recording,'' *JSMPE, 26,* 117 (Feb. 1936).

Silent and Frayne, ''Western Electric Noiseless Recording,'' *JSMPE, 18,* 551 (May 1932).

Hopper, F. L., ''Electrical Networks for Sound Recording,'' *JSMPE, 31,* 443 (Nov. 1938).

Hopper, F. L., ''Corrective Networks,'' *JSMPE, 48,* 253 (Mar. 1947).

Miller and Kimball, ''A Rerecording Console, Associated Circuits, and Constant B Equalizers,'' *JSMPE, 44,* 187 (Sept. 1944).

Grignon, L., ''A Three-Band Variable Equalizer,'' *JSMPE, 46,* 64 (Jan. 1946).

Hilliard, J., ''Report on Recent Activities of the Research Council Committee on Standardization of Theater Sound Projection Equipment Characteristics,'' *JSMPE, 32,* 610 (June 1939).

Frommer, G., ''The Optimum Width of Illumination of the Sound Track in Sound Reproducing Optics,'' *JSMPE, 49,* 361 (Oct. 1947).

Foster, D., ''Effect of Orientation of the Scanning Image on the Quality of the Sound Reproduced from Variable-Width Records,'' *JSMPE, 33,* 502 (Nov. 1939).

Jacobs, A., ''Practical Problems of 16-Mm Sound,'' *JSMPE, 48,* 116 (Feb. 1947).

Goldsmith, L. T., ''Preliminary Report of Research Council Photocell Subcommittee,'' *JSMPE, 48,* 145 (Feb. 1947).

Groves, G. R., ''The Soundman,'' *JSMPE, 48,* 220 (Mar. 1947).

CHAPTER X

Editing and Assembly

Introduction

Editing and assembly are loose and broad terms customarily used to describe the processes that occur between the original records and the release prints. The term *editorial process* is somewhat more precise; it encompasses the combining, cutting, editing, and other preparation of material obtained from the original film material to make the finished motion picture. Since the editorial process is an integral part of the production of a motion picture, planning for it is anticipated in the very beginning—in the script. Precise and detailed instructions—either expressed or implied—are to be found in the script because of the important interrelationships that exist between the original film records and the various copies made from them for the purpose of making the printing masters used for release printing. Although a detailed discussion of the script *per se* is beyond the scope of this book, its technological implications should be mentioned to assure proper dovetailing of all steps in the production of the motion picture.

A script calls for a camera to photograph scenes. A photographed scene is a series of individual pictures corresponding to an uninterrupted sequence of exposures made by a particular camera of some part of the action to be portrayed. For many cases a single camera is used to photograph a scene, since most scenes may be repeated for a "retake" should the action or other factor in the first take be unsatisfactory. Retakes are impracticable in certain kinds of scenes; for example, it would be impracticable to stop a ship in the middle of its launching ways merely because of some photographing difficulty. Such scenes would be "covered" by additional cameras; two cameras similarly placed and with lenses of the same focal length may be used to obtain complete coverage from a particular angle, one camera shooting while the other is being reloaded. Additional cameras may be placed at different locations to obtain closeups: shots taken to show a small area of the subject in great detail; or medium shots: shots that show a larger area than a closeup but smaller area than a long shot. Closeups particularly may be used

as cut-ins: short scenes used to show important detail at a particular stage in the action being portrayed, after which the edited scene returns to the long shot or medium shot portraying the action continuity. In the case of a ship launching, a cut-in might show the breaking of the water and the resulting waves; the story of the ship's gliding to the center of the stream might then be taken up by a medium shot from another vantage point near the end of the ways. In the edited film of a ship launching, the story might start with an establishing shot, a long shot of only a few feet in length that is intended to show where the action takes place. The edited film is a selected assembly of many "bits and pieces" of all kinds, each of which is in itself quite short; to the audience, however, the result is a smooth-flowing continuity in which there is no hint of the many little jerky bits that make up the integrated whole.

Editing—Creative and Physical

There are two aspects to editing: creative and physical. The term *creative editing* implies all the artistic elements, encompassing a thorough understanding of static composition, dynamic composition, color, and their relationships to audience psychology quite as much as an intimate knowledge of the complete physical process of making a motion picture. The term *physical editing* implies the primarily mechanical steps involved in handling the physical materials.

Into creative editing goes the responsibility for selecting not only the "o.k. takes," but also *the* particular take that will be used in the edited picture. The take chosen will be the one that best expresses the desired interpretation of the scene. The creative part of the process must go still farther, it must select the particular frames from each scene that are to appear in the edited film. The magnitude of the job can be appreciated if it is recognized that a single 400-ft. reel contains about 16,000 individual pictures; each frame must be studied to ascertain that it contains just what the editor wants it to contain, and that it does not contain anything that he does not want. A film editor may accomplish this job upon an edited reel in about a week, while the average user of a still picture camera ordinarily does not critically evaluate that many pictures in a lifetime. The result of this herculean effort is unreeled in just a little over 11 minutes.

Since the viewing angle of the motion picture camera is much narrower than that of the human eyes, filmic representation of an event

requires a larger number of scenes than would be required for direct viewing of the event. In general, the representation involves an empirical sequence of shots: first, the establishing shot or long shot, then the medium shot or transition that provides a not-too-abrupt change between the establishing shot and the close-up, and finally, the closeup that shows the detail of interest in the sequence. Additional intermediate shots, such as a medium close-up or an intermediate long shot, may be required if the detail to be portrayed is very small compared with the subject. An example might be the fastenings of a porthole of a steamship where the details of the fastenings are of great importance to the story or subject matter to be portrayed. A full understanding of such matters is implicit in creative editing.

The physical part of the process involves all the physical film handling required to complete the picture. This *must* be done without sensible damage to the priceless original. Since a large amount of even the most careful handling cannot fail to scratch and abrade film seriously, it is obvious that the original should not be handled during editing; rather, the original should be stored under the best physical conditions possible while a copy of the original is used for cutting. A frame-by-frame copy of the original is made (called a work print or answer print). The work print is usually marred seriously, since the job of selecting the desired frames and of placing them in the correct relationship to one another along the film usually requires some "cut-and-try" insertion and removal of frames and very short strips to accomplish the over-all effect in the best possible manner.

Editing Statistics

If a hypothetical subject is to be photographed in color, a color positive original is probably the best original material available. For an average subject, it will be shot 4 or 5 to 1. This ratio represents the relationship of the number of feet used to photograph the original to the number of feet appearing in the release print. Thus, there are about 2000 ft. of film to be viewed, inspected, handled, etc., to provide the 400 ft. that are to appear in the edited reel. To avoid complication in this discussion, it will be assumed that the sound has not been recorded and that it will be done after the picture has been edited.

Since the editor must select particular frames and series of frames from a work print, it will be necessary later to select the exact original frames from which the chosen work-print frames were printed, and to

put them together in the manner required to provide the edited release original. To reduce handling to a minimum, the process ordinarily involves selecting the correct strip from the unedited film and adding it to the end of edited original film that has already been assembled.

Since the work-print cutter's task is to select about 16,000 frames out of 80,000 frames for each reel, it is apparent that the identification and selection of the identical frames from the original by the original-cutter for the purpose of cutting the original into release form will be very difficult and time consuming unless there is positive means of identification of the frame to be selected. Just what the identification system may be and how meticulous and detailed it is depends upon how "tight" the editing is expected to be. If a number of short-length strips are to be used, *e.g.*, 5 to 10 frames, some form of accurate mechanically copied identification is essential, particularly if the original-cutter is someone other than the photographer. "Flash scenes"—abrupt changes in scene of 5 to 10 frames length—are effective in dramatic sequences particularly when used as "cut-ins."

An edited original will probably have about 80 scenes in a 400-ft. roll; a minimum number of scenes might be about 70 and a maximum about 150. The increased tempo of modern living has been reflected in the increase in the number of scenes per reel for Hollywood entertainment films from 20 to well over 100 scenes per reel during the last 20 years. If we consider the average of 80 scenes per reel, the average length of a scene is 5 ft. To edit the film, therefore, it is necessary to select about 80 pieces of an average length of 5 ft. each from some 2000 ft. of original material and to arrange those pieces in correct viewing sequence. The remainder—the discards—are carefully assembled and catalogued for future use elsewhere than in the edited original; some of them may be used for a "stock-shot" library, a library from which background and setting film material may be drawn for future films.

If the edited film has good tempo, it is obvious that some scenes will be quite short and others quite long compared with the average length of 5 feet. The exact length and content of each scene is determined by the editor (or by a cutter working under the direction of the editor) in accordance with the editor's interpretation of the script.

Identification of the Original

If the work print is to be identified in a manner identical to that of the original, markings must appear on the original that can be mechani-

cally copied on the work print when it is made. The identification characters should be easy to read and to interpret; if possible they should be legible to the unaided eye. The identification markings are customarily placed along the perforated edge of the single-perforated film, or along the similar edge of the double-perforated film. The most usual form of identification is edge-numbering.

To facilitate the editing of the picture, it is possible to "footage-number" in the sound track area of a single-perforated film; such markings can be copied on a work print by printing through the sound aperture of a printer. When release prints are to be made from the edited original, no change in procedure is required, since the footage markings appearing in the sound track area are merely ignored. It is apparent that this marking suggestion will function only if single-perforated film is used in the photographing camera, and if no sound is to be recorded on the photographing film.

Edge Numbering

There are two ways to obtain edge-numbered film for an original: (*1*) to purchase raw stock from the film manufacturer so marked, and (*2*) to have the film laboratory edge-number the original by running it through an edge-numbering machine before a work print is made. In both cases the edge-numbers are then printed from the original to the work print.

Edge-numbering* requires consecutive numeral markings at each foot along the film. Since there are 40 frames per foot, this interval may be too long without interim indentification; such interim identification may be accomplished at 10-frame intervals with suitable marks such as a line, an asterisk, a carat, or other index. It is customary to keep records of editing in terms of feet and frames. If the same person who photographs the film edits it, identification and record keeping can be simpler than in the more usual case in which a different person does the editing.

Edge-numbered raw stock is not bought over the counter; it must be ordered in advance. Although film manufacturers customarily edge-number film (when ordered) without extra charge, the numbering operation is an additional and special one that is accomplished after the film has been manufactured but before it is packed and marked for shipment. The order placed with the film supplier customarily specifies the emulsion type desired, the sizes and the mounting of the film rolls, whether the

* Some persons interested in 35-mm optical reduction prefer edge-numbering in intervals of 16 frames (16 frames equals 1 foot in 35-mm film).

film is "single-perforated for sound," or "double-perforated for silent," and that all film shall be of one single emulsion lot number or of lots of closely related and specified lot-difference characteristics. Thus, if an order were placed for 2000 ft., of which 1200 ft. would be provided in "lab packing" in 400-ft. rolls, and the remainder in 200-ft. daylight loading spools, the order might specify: "EK5264-mazda-single perf: 1200 ft. in 400-ft. rolls lab packing; remainder on 200-ft. daylight-loading spools. Total—2000 ft." The order should be written in very clear language, since it is general trade custom that special orders are not subject to return for credit or subject to cancellation.

Film purchases should be planned and orders placed as far ahead as possible. Although film deliveries are usually quite prompt in times of

SHOT LIST   Title ____________________

Cutter ____________ Date ____________

NOTE TO CUTTER: Please fill in first and last columns only. Measure footages from head of title or head of first scene to *start* of each individual scene.

Ftg. to Start of Scene	Scene Ftg.	Scene Time	Time Cue	Scene Description

Fig. 75. Shot list for noting scene lengths and scene descriptions of a film.

normal supply, delays of even several months may be expected in filling special orders in times of short supply. Film manufacturers are usually very cooperative in attempting to meet any reasonable delivery schedule.

Many commercial film laboratories do not have facilities for edge-numbering or for printing edge-numbers. For this reason it is quite important to determine whether such facilities are available and just what they are before production of a film is begun. Such preparation will avoid or at least anticipate difficulties encountered in editing. Such difficulties almost invariably result in a costly waste of time, or an inferior editing job, or both.

When the work print is received from the laboratory, a shot list (Fig. 75) is usually prepared with the exact footage and frame numbers marked

beside a description of the scene; this is cross-checked with the photographing log that was prepared by the cameraman, and with the shooting script. The finished shot list should be accurate to the frame for each and every scene within the film. A film-measuring machine is usually used by the editor for making scene length measurements and for checking the accuracy of the edge-numbering.

One of the most serious mistakes made by the uninitiated film maker is that his identifications are neither complete nor accurate. The importance of accurate identification is "driven home" when the "editor-to-be" remembers that a particular scene and take is among his material, yet he "just can't put his hands on it." Since the piece in question must be found, he winds back and forth through all 2000 ft. of each reel, scrutinizing the frames as they are viewed, to locate the missing scene. This process is wasteful and time-consuming, to say nothing of the wear and tear that it puts upon the disposition of a temperamental would-be editor. Without exacting organization of work procedures, editing would represent almost endless irritating labor, with an unsatisfying and unsatisfactory end product as a result.

Slating

Original photography is often identified by slating. This is merely the photographing of a few frames of an identifying slate before the start of each scene. A slate has identifying information on it, such as the production number, the scene number, the take number, the date, the cameraman's name, etc. All writing is as large as possible consistent with the size of the frame. The slate is photographed so that it appears full frame in height and is readily readable on a film viewer. It would be preferable to have the data legible to the naked eye if possible, but the amount of information within the frame is usually too great to permit this.

The Work Print

A work print or answer print is an exact frame-by-frame copy of an original film with material neither added nor deleted. This is not a complete description of a work print, however, since it does not suggest the picture quality of the work print or give any inkling as to its cost. Incidentally, too, the definition of a work print does not say anything about edge-numbering.

Before the first camera exposes the first foot of film, make certain that

whatever identifying means is used on the original will be copied onto the work print.

Work prints vary in quality and in cost. The prime purpose of a work print is to provide an inexpensive frame-by-frame copy of the original. Since the cheapest copy that can be made is one printed at a single printer light setting on positive stock and developed in a regular positive developer bath, this is a form occasionally used by commercial editors. On such a one-light work copy, the tonal scale is inverted—highlights appearing dark and shadows appearing light—and the picture quality is poor because the contrast of the work print is far higher than would be normal for a good release print. If the picture quality of all cameramen on a production is utterly reliable with regard to all factors, such as exposure consistency and accuracy, color fidelity and lighting, composition, and action, this cheap form of black-and-white work copy may be satisfactory for an editor familiar with the appearance of negative images. Such work prints are made by commercial laboratories, and not by film manufacturers' laboratories (such as those of Eastman, DuPont or Ansco). The price of a one-light work print of this kind is about 2¢ per foot.

A one-light work print of the above kind is not convenient because of its inverted tonal aspect. The next step upward in the cost ladder is the one-light reversal dupe print: a black-and-white print made in the same general manner as the above print except that it is printed on reversal stock and developed by the reversal process. Reversal dupe prints may be made on yellow-dyed other positive-type films as well as on reversal duping stocks. The quality obtained varies with the film used, the developers used, and the processing control. Prices vary too; the average is in the neighborhood of 5¢ per foot. Reversal dupe prints on reversal stock are made by film manufacturers' laboratories. Some commercial laboratories have used Ansco 2250 yellow-dye, high-resolving-power recording stock for making reversal dupes for work prints. The film is developed by the reversal process in much the same manner as reversal duping stock. Since the cost of this stock is one-half or less than the cost of reversal duping stock, the cost of the reversal work print made in this manner represents a material saving. The picture quality obtained is inferior to that obtained with reversal duping stock, but the differences are not important for many editing purposes.

The next step upward in the cost ladder is the one-light color dupe work print. In this work print (more costly but also more convenient)

the copy is not only in color but is printed on color reversal duplicating (duping) stock that provides the correct direction of the picture tonal scale with respect to highlights and shadows. In this print, the density will be correct only for a scene in the original that is correctly exposed; all other scenes will deviate from correct exposure to a greater degree than they did in the assembled original. This class of print is sold both by film manufacturers' laboratories and by commercial laboratories. In general, the film manufacturers' laboratories color-develop all such film because commercial laboratories do not ordinarily operate color film developing machines. The price of this class of print and its quality depends upon where you buy it (a common price is about 12¢ per foot). Within the years to come, it is likely that manufacturers will encourage color-film processing by commercial laboratories to an extended degree. At present, however, such processing accounts for a small percentage of the total color film volume.

Generally speaking, work prints are not timed to correct for exposure variations of the original; ordinarily, timing involves notching the original. Such notching is customarily avoided until the original is edited and ready for release printing.

At this point it is evident that motion pictures are not cheap. It is also evident that there is a significant price difference between a one-light work print on positive stock that was developed in a positive bath and a one-light color dupe work print. (For a one-reel picture, shot 5 to 1, the difference is about $200.) This is usually a big hurdle for the prospective film user because he would like to have the price of the former with the convenience of the latter. A warning should be given at this point: it doesn't pay to cut corners here.

Shipping the Original to Film Manufacturer for Developing

It is apparent from the foregoing that preparations and decisions must be made before the exposed original film is placed in the shipping package for dispatch for developing. The film manufacturer's developing plant is usually very well run. The film manufacturer has learned the importance of utter cleanliness in his manufacturing operations and carries over his experience very deliberately in his 16-mm processing. Variations occur here from time to time and from plant to plant; as in all commercial manufacture, the usual variations characteristic of a manufacturing process are just as evident to a keen observer of film handling as they are in any other manufacturing process. If you

instruct the film manufacturer to make the work print for you, your original can be set aside for storage without opening the shipping cans until you are ready to cut it. From that point on the film manufacturers' laboratories will do little more than make untimed release prints. Timing, cutting, and all sorts of other odd jobs that are needed to finish the picture are in the province of the commercial film laboratory. In many cases commercial laboratories will even do "creative" editing, but usually at rather high prices.

The instructions for developing the original should be quite explicit. Several persons in the film manufacturer's plant will handle your film, and they will know only what you tell them on the attached log sheets and instruction sheets. Instructions particularly should be typed if possible, since handwritten instructions often turn out to be illegible. Shipping instructions should be plainly marked.

The costs of shipment other than ordinary parcel post are borne by the customer. This includes air express or special delivery charges as well as insurance. The one exception is Kodachrome Commercial film, which is customarily sent via special delivery at no extra charge.

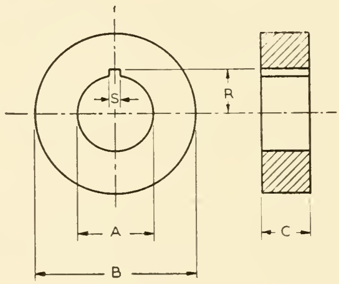
It has been found convenient to splice original rolls together into 400-ft. rolls after processing. It is essential to reduce the amount of handling, particularly in the printing room where the film must be handled mostly by means of the sense of touch. It is customary to make up the rolls in numerical sequence; with such arrangement, the location of particular sequences and sections should not be too difficult when the original film is cut at a later time. Explicit instructions for assembling the original into suitable rolls must be given the film manufacturer's laboratory if camera film rolls shorter than 400 ft. were used.

When the original (which was photographed on Kodachrome Commercial) is returned by the manufacturer, it will be found that the film is mounted on a core and placed in a film can that was sealed with a piece of adhesive sealing tape. Figure 76 is a drawing of the standard core; this is ASA Z22.38-1944. The can used has no holes; the tape effectively seals it and prevents moisture exchange with the outside atmosphere. If the film is to be stored for an extended period of time, the cans should be flat and the film located in a place where the temperature is constant—preferably at about 50°F. When stored in this manner, deterioration is quite slow, and even if the original will not be ready for cutting for as long as 6 months, there need be no cause for concern.

American Standard

Raw Stock Cores For 16-Millimeter Motion Picture Film

ASA
Reg. U. S. Pat. Off.
Z22.38-1944



	Millimeters	Inches
A	25.90 ± 0.20	1.020 ± 0.008
B	50.00 ± 0.25	1 968 ± 0.010
C	15.50 ± 0.50	0.610 ± 0.020
	Recommended Practice	
R	16.70 ± 0.30	0.657 ± 0.012
S	4.00 ± 0.20	0.157 ± 0.008

Bore A to fit freely to hub 25.40 ± 0.1 mm or 1.000 ± 0.004-inch diameter

NOTE: Reprinted August 1946, without change.

Approved May 15, 1944, by the American Standards Association
Sponsor: Society of Motion Picture Engineers

Figure 76

Equipment and Tools of Editing

When the work print arrives, it is first checked to make certain that all material is present and in good order. Should there be any shortages, errors, or film of unsatisfactory picture quality, this is the point at which all such matters are corrected. Ordinarily, if the instructions given are explicit, there is no difficulty on that score. The original is checked and placed in suitable storage.

The problem is now to take the work print—2000 ft. of it that is assembled in 400-ft. rolls, select the 80-odd strips desired, delete from each strip the excess that will not be used, and then assemble the 80 desired sections of strips in the sequence desired for the release print.

Another warning must be given at this point: do not assume that some piece of apparatus that you decide you would like to use is available. In the matter of apparatus for editing, the editor seems to be the forgotten man of the motion picture industry. There are no "standard" methods or apparatus for editing a 16-mm motion picture. Many of the "tools" that the editor decides upon he will build himself—or do without. There are certain items, however, that are used at almost every place that films are edited.

Space

To begin with, space is required. For each individual editing a single film subject, a small room is convenient. This may be as small as 10-ft. square. The room should have painted walls and a painted ceiling; under no circumstances should paint finishes be used that "flake," since dust is a very serious problem with motion pictures. The floor can likewise be painted with a good floor enamel, or it may have a good grade of linoleum. In either event the surface should be smooth so that it may be regularly washed and polished to prevent the collection of even a trace of dust. This first requirement for a cutting room, then, is meticulous cleanliness.

The walls should preferably be painted with a soft pastel shade that will be as easy on the eyes as possible. The editor will be using his eyes all the time in viewing the film; restful wall coloring will not only be a great help physically by easing eyestrain, but will also have a good psychological influence. Light green is one of the most restful colors.

The Work Table

Within the work space, a work table is needed. This may be a makeshift, or it may be one of a variety made for the purpose. The prime re-

quirements are that it shall be easy to keep clean, and shall be convenient with regard to height, etc. Editing furniture and equipment, such as tables, rewinds and flanges, film measuring machines, etc., are specialties for which there are surprisingly few manufacturers.*

Tables and other furniture are made of metal only, and have an easy-to-keep-clean enamel or paint finish. To reduce film scratching to a minimum, it is customary to cover the entire table top with a piece of good "battleship" linoleum cemented firmly in place.

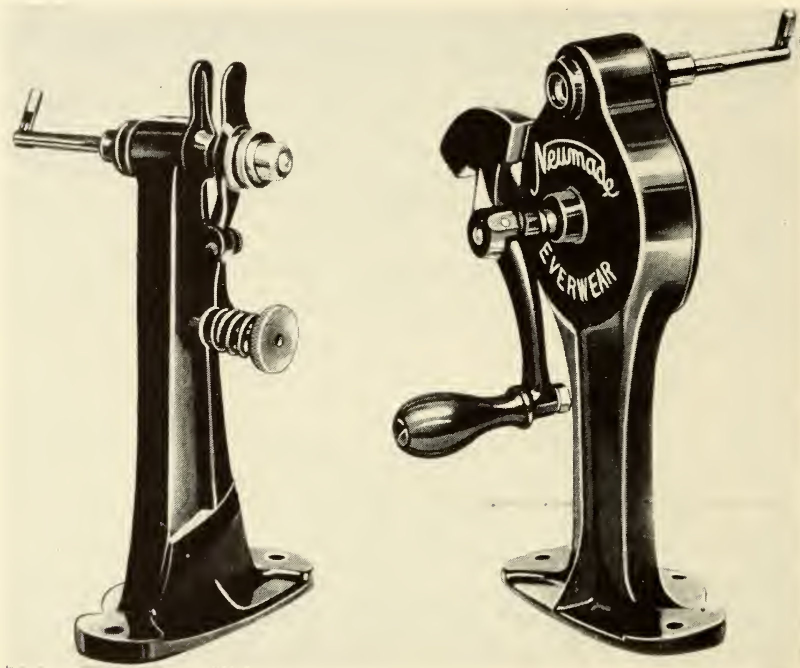


Fig. 77. Neumade 35-mm rewinds that may be used also for 16-mm. Dummy end rewind (left) and live end rewind (right).

Rewinds and Flanges

To rewind film, rewinds are necessary. If film is to be rewound in only one direction, a "live end" rewind and a "dummy" rewind will suffice. The "live end" rewind (Fig. 77—right) is a rewind that has a film-propelling crank. A "dummy" rewind (Fig. 77—left) merely pro-

* Neumade Products Corp. of 427 West 42 Street, New York, N. Y., is one of the few firms that specializes in such material.

vides a mounting spindle without a crank. Since there is often need to wind film back and forth, two "live end" rewinds are customarily used.

Rewinds are made with different spindle contours and in different spindle lengths. One type of 16-mm spindle (Fig. 78), for example, is made to fit a single reel; the reel may be of the "square-round" hole type or of the "square-square" hole type. This spindle cannot be used with a flange, since flanges are customarily designed with a smaller round hole running the length of the hub to cooperate with the shaft of Figure 77. The flange is propelled by a key in the shaft and a keyway in the hub.

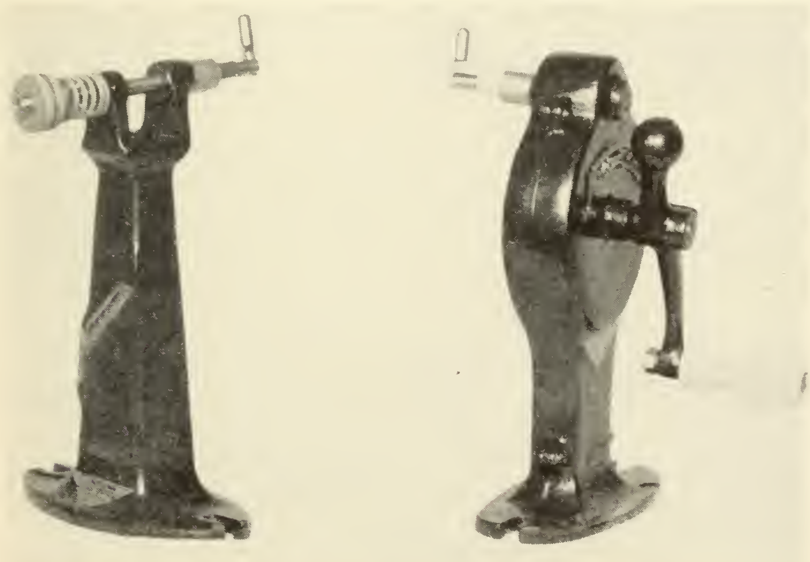


Fig. 78. Dummy end rewind (left) and live end rewind (right) with square-round spindles (for handling one 16-mm reel only).

The dimensions of the hole and of the keyway in the flange are the same as those customarily used in 35-mm projection reels. Figure 78A is the American Standard for Reel Spindles for 16-Mm Projectors.

If film mounted on a core is to be rewound, it will be necessary to use a flange to do it. A flange (Fig. 79) usually consists of two parts: the flange proper (a hub and one end plate), and a cover plate. Fortunately, the dimensions of the 16-mm core have been standardized, although many dimensions of flanges and rewind spindles have not.

Flanges are available in several diameters ranging from 4 in. to about

American Standard

Reel Spindles

for 16-Millimeter Motion Picture Projectors

ASA
Reg. U. S. Pat. Off.
Z22.50-1946

1. Round Section

1.1 The round section of 16-mm motion picture projector reel spindles shall have a finished diameter of 0.312 ± 0.003 inch (7.925 ± 0.076 mm).

2. Square Section

2.1 The square section of 16-mm motion picture projector reel spindles, including finish, shall be 0.312 ± 0.003 inch (7.925 ± 0.076 mm) across the flats. Measurements across the flats shall be made in mutually perpendicular directions.

3. Cumulative Effect of Eccentricity

3.1 The cumulative effect of eccentricity of the round and square sections of the spindles, looseness and misalignment of the bearing, or other mechanical imperfections shall not cause the flange of a tight-fitting reel to depart from the ideal plane by more than 40 minutes of arc.

3.2 A suitable gage for determining the cumulative effect of eccentricity consists of a hub, with coaxial square and round holes whose respective sides and diameter are equal in length, and a flange of suitable stiffness whose diameter is equal to that of an 800-foot reel flange, 10.5 inches (266.7 mm). The flange should be permanently joined to the hub so that its face is perpendicular to the axis of the hub with not more than 0.003 inch (0.076 mm) runout. The hub shall be provided with a thumbscrew for clamping the hub to the reel spindle so that one side of the round and square holes shall come in contact with the corresponding round and square sections of the reel spindle.

4. Reel Position on Spindles

4.1 The design of spindles shall be such that reels are kept under constant lateral pressure against a shoulder on the spindle. The part forming this shoulder need not be integral with the spindle. However, in such event, it shall be securely fastened to the spindle so so that the two parts rotate together.

Approved March 19, 1946, by the American Standards Association

Figure 78A

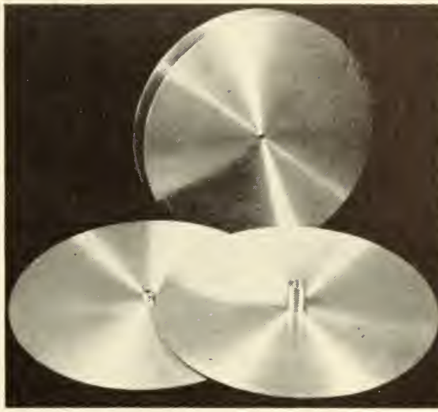


Fig. 79. Two sets of 10-in. diameter 16-mm flanges. The set in the foreground is separated; the flange for film mounting is on the right, the cover flange is on the left. The set shown fits the rewinds of Fig. 77 with the round spindle and key; this type is recommended as the most useful. 16-mm flanges are also available for the 16-mm square-round shaft to fit the rewinds of Fig. 78.

10 in.; the 10-in. size is probably the most useful. For the sake of convenience, it will be desirable to have all rewinds of but a single spindle type; the most useful type is that which cooperates with the flange. Although this type of spindle does not cooperate as well with 16-mm reels as does the special 16-mm, "square-round" spindle, it will function with

Fig. 80. Editing table arrangement.

35-mm reels, 16-mm reels, and with flanges. The spindle (and especially the key) will wear more rapidly when used constantly with 16-mm reels than when used with flanges, but even this wear rate is relatively low. At the worst, periodic replacement of the spindles may be required; such replacement is inexpensive and relatively infrequent.

Several sets of rewinds will probably be needed; just how many and what kind will depend upon how the editor does his work. Figure 80 shows one editing table arrangement that has been found convenient by one commercial organization.

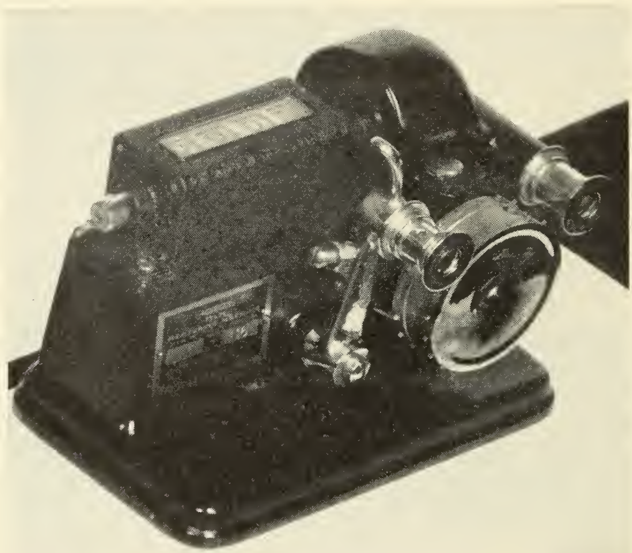


Fig. 81. Single-hub film measuring machine (Neumade).

Footage Counters

A "footage counter," "synchronizer," or "film measuring machine" —three different names for the same kind of device—will be needed to measure film accurately. This device consists of a Veeder counter geared to register accurately in feet when a strip of film is pulled through it. In one common arrangement the sprocket over which the film travels is 20 frames in diameter; two revolutions of the sprocket is exactly one foot of film. Frame markings are provided at the edge of the sprocket to eliminate the need for laboriously counting frames along the film from the footage index mark to the frame in question. A single-hub measuring

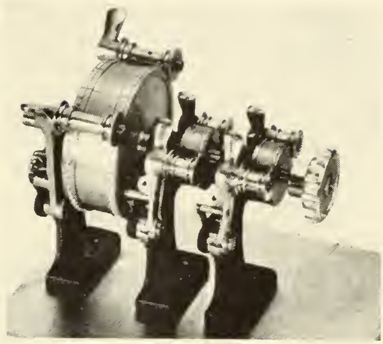


Fig. 82. Combination film measuring machine with one 35-mm hub and two 16-mm hubs (Neumade).

machine (Fig. 81) is a "must"; whether multiple-hub measuring machines (Figs. 82 and 83) are used depends upon what is called for in the script, and upon how the editor does his work.

Reels

The editor will often need reels. Should he use the 400-ft. size, the new Eastman Kodak reels (Fig. 84) are excellent. Should he use the 800-ft. size or larger, either the new Eastman or the Bell and Howell reels (Fig. 85) will be found excellent. In neither case will there be the danger of acquiring nasty cuts, so common from the razor-like edges of cheap reels; such injury is unlikely with those recommended. In buying reels for any purpose, it is good practice to make certain that they meet the essential requirements of American War Standard* Z52.33-1945.

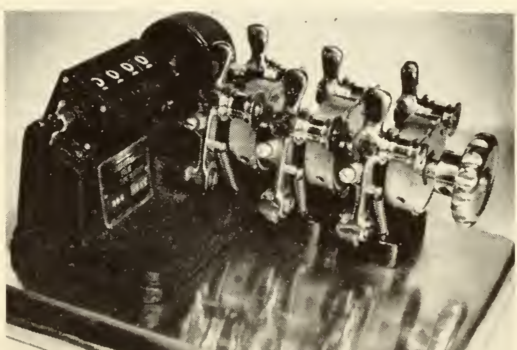


Fig. 83. Triple-hub 16-mm film measuring machine (Neumade). Counter of Neumade HM-5-T reads directly in feet; two revolutions of hub shaft equals 40 frames or 1 ft. Measuring machines are also made with an additional figure at right side of counter showing number of frames (from 0–40).

* This specification is under review, and will later be issued as a new Z22 specification.

Because the average length of a scene is only about 5 ft., 400-ft. reels will be too clumsy for handling the short lengths. Should reels be desirable, the small 50- or 100-ft. reels supplied by film manufacturers (as the mounting for film just returned from processing) are quite handy. This reel has the conventional "square-round" hole combination when supplied by Eastman Kodak and the "square-square" hole combination when supplied by Ansco.

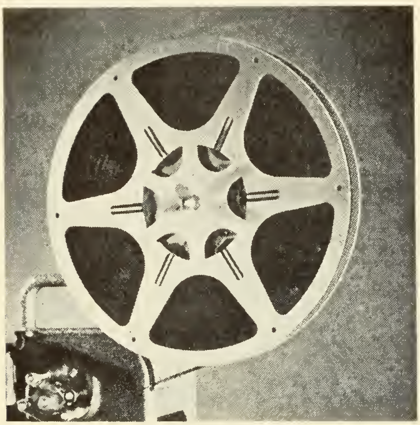


Fig. 84. An excellent 400-ft. film reel (Eastman Kodak). Recommended as feed reel for all 16-mm projectors that accommodate it and as takeup reel for 16-mm silent projectors that accommodate it as maximum size. No commercial 400-ft. reel can be recommended for takeup use with 16-mm sound projectors that accommodate reels of 1600 ft. and larger (in this case the Bell and Howell 800-ft. reel is recommended).

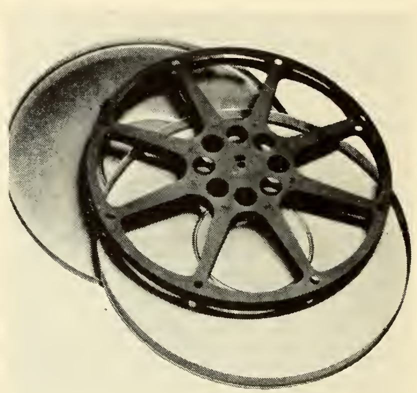


Fig. 85. An excellent 1600-ft. film reel —with film can (Bell and Howell). The core diameter of $4\frac{7}{8}$ in. used for this reel is also used for the Bell and Howell 800-ft. and 1200-ft. sizes. The use of such reels on commercial 16-mm sound projectors assures minimum film damage arising from reels. For costly prints such as Kodachrome sound prints the use of cheaper reels cannot be justified.

To handle a large number of short pieces of film requires some convenient means of storage. One simple arrangement is to nail 1 in. by 2 in. boards along the wall; long nails are driven into the boards about 4 in. apart. With this arrangement each nail is used to hold a 100-ft. reel. Possibly 10 boards with about 20 nails per board will be a convenient arrangement; the boards are arranged vertically with respect to one another. A suggested arrangement is to have the boards at the left end of the editing table, and the waste barrel at the right end; the work table in

this case should preferably be small so that the editor does not need to leave his work stool.

Filmviewer

For viewing the film at the editing table a filmviewer is necessary. The filmviewer has a small lamp as a light source (about 50 watts or so), and a simple optical system for projecting the picture to a self-contained and partially hooded ground glass screen. An integral part of every filmviewer is a small rotating shutter or prism that cuts off the

Fig. 86. Model LP 16-mm picture Moviola. This machine uses a 50-watt projection lamp. Moviolas are also manufactured with an Eastman projection screen attachment consisting of a light metal box containing a projection lens, mirrors, means for focussing, and an Eastman rear-projection screen 2″ by 2¾″. The space between the film and the projection lens is accessible, so that the film can be marked with a grease pencil without opening the film gate. Moviolas made for 16-mm, like 35-mm Moviolas, may be obtained with sound on separate film, sound on the same film, or both.

light from the screen while the film moves along from one frame to the next. The Eastman filmviewer is excellent, but the image is inconveniently small for professional editing. Both the Craig and the Bell and Howell provide larger and more convenient images. Other filmviewers have made their appearance on the ciné equipment market; the Moviola LP (Fig. 86) is typical of the more costly professional types.

After the filmviewer has done its work and a rough cut is assembled, it is desirable for the editor to view the film by projection in order to ascertain that there is no feature of the film bits that he has selected that is undesirable. Since the filmviewers can not show image detail satis-

factorily, it is at this point that the editor checks such detail minutely by screening the film in a projection room under good viewing conditions. If fineness of detail is to be checked, the editor will ordinarily view the film at a distance of about 2.5 w from the screen to make certain that he can see all that is significant (see Chapter XIII).

Splicers

A film splicer is needed to splice the short pieces together into a roll of approximately 400 ft. In splicing a work print, it is not necessary to be as "finicky" about cleanliness, neatness, etc., as it is in splicing other film such as original photography, but it is desirable as a habit. This does not mean that a splice may be carelessly made; it does mean that the very accurately maintained splicers that make a hot splice are not needed

Fig. 87. Griswold Jr. 16-mm film splicer (HM-6). There are two Griswold 16-mm splicers available, the HM-6 (Jr.) and the R-3 (Professional 8–16 mm); both provide a non-symmetrical splice; and are available for splice widths of $\frac{1}{10}$ in. and $\frac{1}{16}$ in. $\frac{1}{10}$ in. is supplied unless otherwise specified.

here. A splicer such as the Griswold Jr. (Fig. 87) that turns out a splice approximately 0.070 in. wide is suitable.

There are many splicers on the market at various prices, ranging from \$5 to over \$1000. Most of the lower priced splicers are made for amateurs. A number pay little or no attention to standards, and some are quite flimsy and are made from stampings rather than from castings. In the lower price range the Griswold is one of the best; it is sturdy and keeps its adjustment quite well. Its price is about \$20. With the Griswold, the splice overlap occurs entirely within one of the spliced frames; it does not overlap symmetrically about the sprocket hole.

If any appreciable amount of splicing is contemplated, splicers should be checked carefully, since there are some excellent machines on the market, such as the Bell and Howell laboratory-type combination 35-mm and 16-mm splicer (Fig. 88) that makes a straight splice. This is an excellent machine and is well worth its price of about \$1300 because of its ease of operation and its mechanical accuracy. It is convenient to op-

Fig. 88. Bell and Howell combination 35-mm and 16-mm laboratory type splicer. This splicer is built with a heater that accelerates splice drying. It is the type of splicer most widely used for applications where large numbers of good splices are required.

erate, and an operator can make many more good splices per hour than with other manual splicers. Figure 88A is another view.

For many years 16-mm splicing was looked upon as a necessary evil, and little real improvement in 16-mm splicing methods occurred. One of the sources of difficulty was that a single form of 16-mm splice was used for all kinds of 16-mm films. A casual study of the dimensions of the 16-mm splice in relation to frame dimensions indicates that most ordinary forms of splice encroach upon the picture area. This is true of even the narrowest straight splice of approximately 0.070-in. width. (See Fig. 89.)

Recently, the Society of Motion Picture Engineers has renewed interest in the subject, and several new improvements in splicing methods have been suggested. Each is directed to the solution of a specific splicing

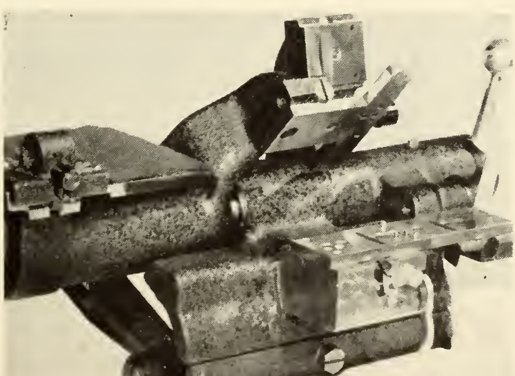
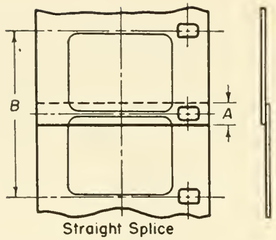


Fig. 88A. Closeup of Bell and Howell splicing head of Figure 88.



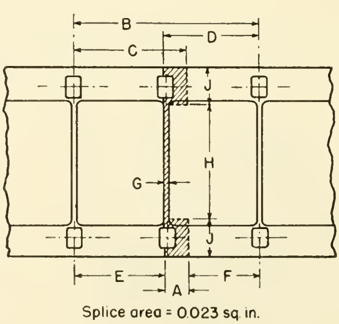
	In.	Mm.
A (max)	0.070	1.78
B	0.600	15.24

Note A. Dimension *A* is maximum and a narrower width splice of adequate strength is desirable.
Note B. The straight splice is symmetrical about the included perforation.

Fig. 89. 16-mm splice recommended for general professional use.

problem rather than a "shotgun" attempt to apply to all stages of film making. One suggestion has been made by Baumert and Noble* (Fig. 90) to alter the dimensions of the splice for assembling an original 16-mm film in order to make the splice invisible by eliminating its encroachment. Another suggestion has been made to use a scotch tape wrapping around the butt ends of two pieces of films to be joined for a work print, punching a sprocket hole in the scotch tape so that the film will run through a filmviewer, a projector, moviola, or other machine used for editing. The large increase in the volume of 16-mm film used each year is now directing more attention to the problem of splicing, and it is likely that new splicing machines and methods will find their way to the market in the near future.

Mention should be made of the Bell and Howell diagonal splice that



	Mm.	Inch Equiv.
A	1.99	0.079
B	15.24	0.600
C	9.42	0.31
D	7.82	0.308
E	7.41	0.292
F	5.81	0.229
G	0.40	0.016
H	9.67	0.381
J	3.16	0.1245

Fig. 90. Baumert-Noble invisible 16-mm splice. The dimensions of this splice are chosen to avoid the printed evidence of a picture splice. It is especially advantageous for picture originals and for intermediate picture copies such as dupe negatives and Kodachrome intermediate dupes.

* Baumert and Noble "An Invisible 16-Mm Splice," *JSMPE, 49,* 232 (Mar. 1947).

is made by certain of the Bell and Howell laboratory splicing machines. This splicer has found some favor for 35-mm sound track, but not equally for 16-mm sound track. A diagonal splice should never be used in an original film; opinion as to its use in release prints is divided, since the splice appears diagonally across the frame of the picture and causes a "flash" on the screen as it passes through the picture gate of the projector. The present trend seems to be away from diagonal splices in 16-mm.

Film Cement

To splice film requires film cement. Because of the differences in chemical composition and properties, film-base materials made by different manufacturers do not adhere equally well when cemented with different film cements. Eastman safety film cement should be used for Eastman film; for other films, information may be obtained by writing the manufacturer.*

Cutting the Original

Cutting the original to match the edited work print is done with gloves—in both the figurative and in the literal sense. The original is never handled with bare hands because of the dirt, oil, and other contaminants always found on even the cleanest hands; a pair of clean, soft, washable, cotton gloves is used. An active editor will use several pairs of gloves in a day, making certain that the gloves are carefully laundered once they have been used. Needless to say gloves should be lint-free so that there will be no foreign matter present which may affect the original film. If all editing has been very carefully done and all film in the work print and all related film in the original can be identified, it is better practice for the inexperienced not to touch the original at all. It should be taken to the commercial film laboratory for assembly and cutting of the original. It is customary to charge for such labor at a cost of several dollars per hour, but it is well worth it. Experience in handling film may be acquired by watching the laboratory personnel, who are active and quick and who have through experience worked out a number of rule-of-thumb methods of handling film with the least effort and with the least film damage. Care should be exercised that the film is left only in a spotless plant that has spic-and-span personnel.

* The excellent Eastman booklet *The Handling, Repair, and Storage of 16-Mm Films* (*KP 2–45*) should be in the hands of anyone who has occasion to make splices.

Cutters especially take pride in their work, and there need not be any hesitation in asking questions as to why a certain operation is performed in the way it was done. Their neatness in all that they do is legend in the industry.

Preparing for Sound Recording

After the work print has been edited into its final form, the editor prepares a shot list.* The shot list is merely an accurate listing of each scene in the film arranged in correct sequence. The length measurement in feet and frames accumulated to the first frame of the scene listed is noted in addition to a brief scene description. From this shot list a commentary can be prepared that will fit the picture exactly with regard to timing. In this listing, the scene length is merely the difference in measured length between the beginning and the end of a scene. The time cue listed is merely the time equivalent to the measured length at the beginning of a scene; it is indicated in minutes and seconds and is calculated on the basis that there are 40 frames per foot and 24 frames per second. Since such conversions are made often, it will be found useful to prepare a conversion table. Synchronism errors of even 0.1 second can occasionally be detected by keen observers, so that it is customary to list tenth-second time intervals in the table.

After the sound script or commentary is prepared, the work print is used in the scoring projector when sound recording is to take place. Since most 16-mm projectors do not have geared synchronous motor drive, they cannot be used without some addition or modification. Bell and Howell, one projector manufacturer, does supply a small synchronous motor drive that can be attached to the shutter shaft of the projector that is on the front of the machine. In order to assure that the attachment will function satisfactorily it will often be necessary to return the projector to the Bell and Howell service station for fitting. When recording is in progress, it will be unnecessary for the commentator to turn his glance alternately between the script and the screen. The time cue listed on the script and a convenient stop watch satisfactorily take care of the timing requirement if the commentator will merely start the description or comment upon each scene at the precise moment that the time cue indicates the start of the scene.

* Clemenger and Wood, "16-Mm Equipment and Practice in Commercial Film Production, *JSMPE*, *34*, 555 (June 1940) (see Fig. 75).

When recording is under way, it is well to remember that it is usually far easier to get the film timing correct during the recording session than it is to attempt to correct it by "juggling" the sound track later on. 16-mm sound cutting is unsatisfactory at best; not only is good blooping a serious problem if the editor must rely upon paint-outs (as he usually does), but also the relatively long spacing between sprocket holes makes it next to impossible to alter syllables as can be done occasionally with 35-mm film.

Synchronizing Sound and Picture

To avoid confusion, a standard system of marking the picture film and the sound film for synchronism has been established.* The editor is responsible for the synchronization of the picture film and of the sound film, and when synchronization has been established, the standard marks should appear on the work print of the picture and the work print of the sound track. Once these marks have been transferred to the cut originals no difficulty with synchronization should be experienced, since errors in printing and other laboratory operations (should they occur) can be traced readily.

No pre-view head arrangement for checking the "syncing" of separate picture and track is as yet available on the open market. Several arrangements are workable; a good suggestion is to check with the commercial film laboratory that will do your release printing. They may not have the equipment that you need, but they can make a number of useful suggestions.

In the foregoing, the subject of titles for the film and effects for the film (should they be needed) has not been discussed. Titles can be quite "arty" and expensive, and they can also be simple and inexpensive. A good title requires good art work and good title camera work. There are numerous specialists in most every locality.

In conclusion, a remark made earlier in this chapter bears repetition: the editor is the forgotten man of motion pictures. There are no standard methods or apparatus for editing a motion picture. Many of the things that the editor needs, he will have to build himself or have someone else build for him; if he doesn't, he'll do without. Manufacturers would do well to hearken to the needs of this no-man's land of motion pictures; the equipment of the cutting room needs scrutinizing—and improvement.

* American War Standard Z52.53-1945.

Selected Bibliography

1936–1945

"Editing," pages 85 and 86.

Collected Papers on Navy Training Films, Goldner, Roberts, Dresser *et al. JSMPE, 43* (Nov. 1944).

For additional references the reader should refer to the following indexes to the *Journal of the Society of Motion Picture Engineers.*

January 1930–December 1935

"Editing," page 23.

CHAPTER XI

Preservation and Storage

Introduction

If past experience may be considered a guide, most film makers underestimate the usefulness of the films they have made. On the whole, the film maker customarily thinks only in terms of an immediate need for a particular film. The result of this lack of foresight is the lack of availability of prints of good technical quality from older subjects. In too many cases the result is the lack of any prints whatsoever because of the loss of the original or because the original is so badly damaged that it will not even go through a printer. Frantic and unsuccessful hunting for an unmarred print of a subject as little as two years after the date of its completion has been all too common an occurrence in 16-mm films. It has been somewhat less common in 35-mm films, in all likelihood because 35-mm are nitrate-base films that must be stored in fireproof vaults. Many 35-mm films would probably also receive the "out of sight, out of mind" treatment if the fire laws did not demand storage with suitable protection against fire.

It has been said that the maturity of an age can be judged quickly by the amount of recorded material that is purposefully preserved for a future time. The very rapid growth of the use of photography and its familiarity to almost every citizen through the still camera, through the motion picture camera, or through the commercial movies, is beginning to usher in a new era in the recording of history, an era of purposefully recording in films the ideas that we wish to convey to others of our own generation and to generations to come. Even family histories are now beginning to be recorded in home color movies—supplementing the familiar family photograph album.

Often a film starts out as a personal thing and concerns but a single person or a very small group. If the film records information of interest to a large number (as is often the case, *e.g.*, in hobby films), it should be available to a larger group. If it is of scientific interest, for example, there is a British organization, the Scientific Film Association, that is

interested in reviewing it and in obtaining a copy for free distribution to its members through its central library regardless of the country of origin. More recently, a Canadian Scientific Film Association was founded, and an international association was recently established.

Present Status

If material is to be preserved, there must be a plan to accomplish the preservation. Ordinarily, we are so concerned with matters of the moment that seem so much more pressing, that the question of preservation of the original receives little attention that results in beneficial action.

The major national preservation efforts in the United States are those of the Museum of Modern Art and of the National Archives; both have been in operation for more than a decade. More recently, the Library of Congress has instituted an acquisition program to broaden the scope of the Government collection and its functions. With regard to specialized films made by individual investigators, however, no solution is being considered in these organizations, not only because of meager budgets, but also because they have not yet been able to concern themselves with films that have a specialized and limited scope of interest. Such films are but one of a large variety of nontheatrical films with long-term value.

Preservation over long periods of time is a subject beyond the scope of this book. Preservation over shorter periods of 5 to 10 years, for example, can be accomplished with relatively simple measures. These will be described in broad outline.

Preservation of the Original

Handling of the original should be kept to an absolute minimum. The original should *never* be run in a projector. A film that is handled carelessly will not last even six months; too often an original has been torn to shreds before it has outlived its usefulness. The primary cause is that the deterioration caused in each handling is uncontrolled and often even unknown.

Too often the owner of an original places the priceless original in the custody of a film laboratory or other nominal caretaker, where each handling causes deterioration the extent of which is unknown. Too often the accumulated effect of individual handlings only becomes evident when an attempt is made to project a newly made print on a screen somewhat larger and brighter than usual, or under other more critical projection

conditions. At this point, however, nothing can be done about it and the projection is not as satisfactory as it should be.

Three Stages of Storage

Webster's dictionary defines "preservation" as *the act or process of preserving or keeping from injury or decay.* In terms of a 16-mm film, the objective, therefore, is "to keep and save the originals from injury and decay" and, at the same time, provide copies for use that are derived from the originals. It therefore follows that the release prints shall be made from intermediate copies during the period when the originals are in suitable storage.

The general method is not new; a modification of it has been used for years by the entertainment motion picture industry. Briefly, there are three stages of storage.

Stage 1. The originals (in the custody of the owner) are in "dead" storage under suitable conditions. (Temperature constant—maintained in the range from 40° to 50° F.)

Stage 2. The intermediate copies (in the custody of the laboratory or other processor) are in "live" storage under the most suitable conditions practicable, yet assuring their ready availability for the making of release prints. The intermediate copies are used to provide release prints.

Stage 3. The release prints are available for ready use for distribution yet stored under the most suitable conditions practicable—consistent with ready availability. (Temperature changes above room temperature, especially, to be avoided where possible.)

In each stage listed, responsibility for storage falls upon the individuals logically responsible. The owners are responsible for the originals, the laboratory is responsible for the intermediate copies, and the library or other user is responsible for the prints. This arrangement has all the advantages of the customary handling of "protection prints," with the further advantage that possible damage or loss is anticipated.

Mechanics of the Method

The mechanics of the method are simple. Once each year the originals are withdrawn from storage. The film owner at that time advises the laboratory or processor of the probable requirements for release prints for the forthcoming year. The laboratory is then asked to make up *all* intermediate copies required for a full year's operation; these are printed or otherwise derived directly from the originals. All intermediate copies are made up at one time.

As soon as the intermediate copies are completed, the originals are returned to the owner for Stage 1 storage for the forthcoming year. This storage presumes the best conditions possible, but are rarely assured merely by the appearance of a warehouse bill once each month. For 16-mm originals, storage may be quite simple, and suitable conditions will be described later in this chapter. The important feature of the method is that the originals shall remain in dead storage for a very long time compared with the time that they are in use. Storage for 51 weeks of a year and use during one week of the year would represent a typical schedule.

It may well happen that the owner of a film will underestimate (or overestimate) his probable need for prints during a particular year. This does not void the usefulness of the method if the film remains in dead storage for a large percentage of the time. If accurate records are kept for a year or two, it will be surprising how accurately the need for a particular film may be estimated.

Print Quality

It should be obvious that consistent quality should be expected in *all* prints manufactured, not merely good prints in the sample first lot. With the original suitably preserved and with one acceptable reference print of the subject on hand in the library, it should be an easy matter to check the quality of release prints made by one laboratory with those of another, or to check the quality obtained at one time with that obtained at another. Because an original is often edge-notched* for release printing and there is no standardization of either the size or of the relative location of a printing notch, it is wise to select, and remain with, the best possible film laboratory for your work.

As has been pointed out in an earlier chapter, there is a serious loss of print quality in every step in making a release print. The suggested method of preservation implies two additional generations of prints, the intermediate copy made directly from the original, the second generation, and the release print, the third generation. Unless good practices and control are used, the quality of a third generation print is likely to be poor. Even though the minimum losses in each copying and processing step are quite high, good print quality can still be obtained

* An original film is edge-notched in release printing for the purpose of actuating a sensitive switch, controlled by a roller that rides the edge of the film, which switch causes the light-change mechanism of the printing machine to function.

if the original was of excellent quality and if fine-grain films are used under optimal conditions; good print quality cannot be obtained if there is carelessness or poor control. The importance of control is especially important in making third generation color prints; it must be quite precise to obtain satisfactory prints. Not only is the resolving power of color film appreciably less than that of the black-and-white film, but also the human eye has greater sensitivity to small color differences than it has to small intensity differences. Since the only step in the print-making process under the control of the commercial laboratory is the exposure of the copy, every step must be taken to reduce resolving power losses in color printing to a minimum and to obtain accurate exposure control both as to intensity and as to chromatic quality. Good, or even acceptable, third generation color prints are quite rare. Where they are obtained, good control has been exercised, and in all likelihood the colors to be differentiated are well separated in the spectrum, and located somewhat centrally in the three color band ranges.

If the duplicating process is not under very close day-to-day control, it may not be possible to produce satisfactory third generation prints. Should this be the case, it would then be necessary to make all the prints desired at one time for the yearly period, storing the original for the remainder of the year under proper conditions as soon as printing is completed.

Number of Copies from an Original

Before determining the number of copies that can be made from any particular original, it is well to review what determines the end point in the life of an original film, and how it is affected by printing or other copying procedures.

One of the sources of film deterioration is the deterioration that will occur while the film lies unused on the shelf. This deterioration, although cumulative, is very slow with present-day safety films that have been stored properly. The major source of deterioration of a film in constant demand and use is wear and tear that results from handling. This is the important source in the average case in which a large number of prints is required.

When a film is handled for editing and splicing, it acquires minute scratches and abrasions that are likely to be serious if the film has been handled carelessly. In addition, every time the film is removed from its can for printing it acquires further scratches and abrasions.

Before it is actually printed, it should be cleaned. Cleaning consists of wiping away the surface dust and dirt with very good facial tissue (similar in quality to lens tissue) soaked in carbon tetrachloride. The tissue is usually folded in a piece of silk velvet to prevent the hand of the cleaner from touching the film. When the film has been satisfactorily cleaned in this manner, it is rubbed once more with the silk velvet to remove traces of lint that may have been left behind by the tissue.

Each such handling adds additional tiny scratches and abrasions to the film. Some laboratories do not bother to clean the film before it is printed, and the dirt accumulated by the original is copied onto all subsequent prints. Other laboratories try to use machine cleaning, but, unfortunately, there are very few cleaning machines that do not add scratches and abrasions far more quickly than the laborious and more expensive hand cleaning. In any event, every handling adds deterioration; the amount of deterioration varies with the cleanliness of the place in which the film is handled and the skill and care of its personnel.

The operations of the laboratory—particularly in the printing room—add their important share to the scratches and abrasions added to the film. If the film path is not kept scrupulously clean and the hardened stainless steel gate or chromium-plated film path with which the film is in contact is not kept mirror-smooth, still more scratches and abrasions are added. A particle of dirt lodged in the film gate of a printer does just as much damage as a like particle of dirt lodged in the gate of a camera; it scratches the film as a diamond cuts a piece of glass. If the machine starts with a jerk or has been improperly threaded, a large amount of damage is done in a single trip through the printer.

The printing room can add still more mars by its manner of handling the precious film. In some laboratories the printers run in only one direction. When the end of a reel is reached, the film must be rewound—usually in the dark—in order to make the next print. Rewinding is done by hand or by machine. Hand rewinding is slow and tedious if it is well done, and is costly in terms of labor. Rewinding by machine is usually faster and less costly, but is usually considerably more damaging than the printing operation itself. Although printer operators are quite careful, the amount of scratching and abrasion added to the film by a rewinding, however accomplished, and by the threading of the machine is ordinarily appreciably greater than that added when the film is run through the printer several times. If a machine runs at high speed, it is far

more likely to mar the film, all other things being equal, than if it runs at low speed. High-speed operation of printers is very common today as will be noted in the next chapter; this is usually necessary to bring down print prices.

It is apparent from the foregoing that the cumulative deterioration that occurs with each step of film handling is most important. Generally speaking, the end-point of a film is reached when it is scratched, abraded, and otherwise physically damaged to a certain arbitrary point beyond which it is not suitable for making prints. The deterioration per unit handling varies over very wide ranges from laboratory to laboratory and often varies over wide ranges at different times. Unfortunately, there is no simple standard measure by which this deterioration can be measured. Because it is cumulative and gradual, its presence is rarely appreciated until too late.

Some laboratories have made 50 copies of a particular piece of film before deterioration began to be noticeable and the end-point was reached. More recently, as many as 200 to 300 copies have been made under similar conditions. With really good care and with the elimination of almost every possible source of avoidable deterioration, as many as 700 to 800 copies of a particular piece have been made. If the picture quality on test prints proves satisfactory, it is obvious in the first case that for a third generation print, 50 times 50 or 2500 prints would be possible. For the laboratory where 250 copies were made, 250 times 250 or 62,500 prints would be possible. In that very, very rare laboratory under rare conditions where 800 prints were made, 800 times 800 or 640,000 prints would be possible. What is extremely important is to keep the quality loss at an absolute minimum between the original and the intermediate copies, so that third generation prints are satisfactory for release prints. In this manner, any ordinary film, if the original is properly preserved, can be expected to provide all the release prints that may be required of it during its ordinary useful life. This is in sharp distinction to the too-frequent situation in which valuable originals are irretrievably ruined in as little as six months of their useful life. In practice, almost any laboratory should be able to turn out 50 copies from a particular piece of new film without reaching the life end-point. How much farther a particular laboratory can go depends in great measure upon how important care in film handling is considered, and how much time and effort are spent to obtain the desired result.

Storage Recommendations

It is advisable to follow the recommendations of film manufacturers closely. For Kodachrome, it is first necessary to clean the film lightly yet thoroughly; carbon tetrachloride (Carbona) applied sparingly is probably the best cleaning agent. After cleaning, the film should be wound firmly and smoothly on a core without cinching, and placed in an ordinary metal film can. Cleaning and packing is best done in a dust-free air-conditioned room where the temperature is near 65° or 70°F. and the relative humidity near 40%.

The film cans are identified and then sealed; an adhesive tape is good for the purpose, since it will seal the can quite thoroughly. A suggested sealing would be two turns of "Scotch tape" on the underside and two turns of Kodatape or similar adhesive over the "Scotch tape." It is preferable to use film cans that do not have any holes; should holes be present, it is necessary to seal them so that no moisture exchange may occur between the outside atmosphere and the atmosphere within the can. The more thorough the seal, the slower the deterioration of the Kodachrome under the conditions specified. After sealing, the cans are placed in an electric refrigerator or other cooled space where the temperature can be maintained at 45° to 50°F.; the temperature should be as nearly constant as possible.

For the sound track original more elaborate precautions may need to be employed; this depends upon how well the original was developed. Fortunately, the shrinkage and loss of flexibility with age of Eastman 5372 are not very serious if the film is kept well sealed. The major deterioration to be avoided is image deterioration which is aggravated by excess residual hypo that results from insufficient and improper washing of the film after developing and fixing. Another result of "cheap developing" to be avoided is improper drying. The most obvious cure for this kind of situation is to have the film properly developed, washed, and dried when it is first developed in the laboratory.

The sound film should first be permitted to become moisture-stabilized with the surrounding atmosphere of 65° or 70° F. and 40% relative humidity. Film that is loosely wound and left in an unsealed can will become moisture-stabilized in about 24 hours. When ready, the film should be identified, and sealed* in the manner similar to that used for Kodachrome.

* These instructions do not apply to nitrate-base films. *Under no circumstances* should nitrate base films be sealed, since the by-products of nitrate film deterioration are toxic and explosive.

Even such a simple storage technique is adequate for *safety*-base films such as 16-mm, since the additional effectiveness of further measures is doubtful and costly. Until such time as the more complicated procedures justify their high costs, they may be looked upon with suspicion.

In storing color films such as Kodachrome and AnscoColor it should be noted that the dyes of these films are fugitive. Deterioration is quite slow if stored as recommended. In the event that long-term preservation is needed, separation negatives may be made on a black-and-white film such as Eastman 5203. Further information may be obtained directly from the film manufacturer. It is usually a good plan to provide such information as the emulsion lot number and emulsion number, and any processing numbers that will establish the date on which the film was processed and the particular color-developing laboratory concerned. Manufacturers keep accurate manufacturing and processing logs of their operations and can provide special suggestions should it become necessary to compensate for some slight deviation from the theoretical norm.

Preservation plans should be made before the first camera exposes the first frame of film. When this is done, the disappointment that comes from the rapid and uncontrolled deterioration of the original is avoided, and print consistency, usually next to impossible without suitable planning, becomes practicable. Preservation for a period of 5 to 10 years under the suggested conditions is practicable with present-day materials. Should preservation over longer periods be desired, great care in all handling and storage of the film will be required. Suggestions on preservation should be sought in such cases from the manufacturers of the film materials concerned.

Selected Bibliography

For bibliographic material the reader is referred to the following indexes to the *Journal of the Society of Motion Picture Engineers.*

July 1916–June 1930

''Film Preservation,'' page 128.

January 1930–December 1935

''Film Preservation,'' page 26.

''Film, Storage,'' page 26.

1936–1945

''Film, Storage and Preservation,'' page 92.

''SMPE Activities, Film Preservation Reports,'' page 128.

CHAPTER XII

Processing and Release Printing

Introduction

A reasonable way to think of the subject of processing and release printing is to consider it as consisting of everything between that which is on hand, the original picture and the original sound track, and that which is wanted, the release prints.

The modern motion picture processing machine* is a device to transport continuous lengths of motion picture film through the several chemical and physical operations that produce a permanent visible image from the latent image impressed on the film during exposure.

In general, a laboratory represents the investment of a goodly sum of money and also involves high fixed charges and overhead; therefore, it is usually "geared up" for repetitive processes such as the making of large numbers of release prints. Other activities are, for the most part, merely aids in the manufacture of these release prints. Printing machines for release printing as well as developing machines usually operate at high speed. To reduce handling, some laboratories have special printing machines which will print forward and, after the film has run through, will run rearward—thereby eliminating the need for rewinding the films being copied. To reduce manual handling still further, another feature is added; the special printer is also designed to print picture at one aperture and sound at another aperture during a single operation. In the mass release printing of 35-mm composite sound prints, laboratories have gone even farther; directionally reversible printers of composite prints feed developing machines directly, and the developed prints are inspected by high-speed inspection projectors which project the film just developed. Over a decade ago the operating speed of one installation was about 150 ft. per minute for the developing machine which ran at substantially constant speed; the printer ran at 180 ft. per minute as did the inspection projector. The higher running speeds of the printer and of the projector were necessary to allow for the removal of printed rolls of film, and the installing of fresh rolls of raw stock in the

*Definition furnished by J. Stott.

printer, and for the removal of inspected rolls of printed and developed film from the inspection projector. This kind of operation is common in the larger laboratories. Some of its features are now being adapted to high-speed 16-mm release printing.

To increase machine output for the purpose of cutting printing costs still further, one laboratory has built within its own organization special multihead printers. One such machine causes the preprint film to run successively through 7 different printing heads, at each of which a roll of raw stock is printed; thus 7 prints are exposed in a single trip of the preprint material through the printing machine.

Another expedient employed by the same laboratory is to make two combined 16-mm dupe negatives side-by-side on the same film, using the 32-mm width to make a 32-mm release print. After the print comes off the developing machine the 32-mm film is slit, providing two 16-mm prints with the handling of but a single strip of film during the 32-mm portions of the manufacturing process.

The trend in this direction is being accelerated by the relatively great increase in film laboratory wages that has taken place in the last decade. The price of release print raw stock for black-and-white printing has changed relatively little during the last decade; more recently, prices have moved upward. As competition tends to drive down print prices, it is obvious that the saving must be made by sharply cutting the man-hours of labor needed to produce release prints. 16-mm release prints in bulk are now sold at lower prices than those of a decade ago despite the large increases in labor cost and relatively smaller increases in the costs of film, chemicals, electric power, water, and machinery. The effectiveness of the improved production efficiency due to methods and equipment improvements, can hardly be challenged.

Because of the large number of operations that must be performed in the making of a release print, it is imperative that manual handling be reduced to an absolute minimum. This has reached the point where price differences reflect strongly the amount of "can-carrying" or other internal manual transport that goes on inside the laboratory.

Since laboratories are so cost-conscious, it is obvious that a film must be completely and meticulously prepared for developing and printing before it enters the release-printing operation proper. Errors must be eliminated beforehand, because once the film is on its way, it becomes almost impossible to catch an error, because of the speed with which laboratory mechanical operations are performed. Thus, if a film has started

through a developing machine, it is as good as developed; if it has started through a printer, it is as good as printed. In the former case it is not practicable to stop the machine to remove film that has started through; in the latter, while it is less difficult, it is still impracticable. In either case, no laboratory manager will permit an interruption of that extent in his production schedule.

A discussion of film manufacturers' laboratories and their internal operations is beyond the scope of this book. Suffice it to say that they are customarily very efficient organizations with facilities at their command that are the envy of the independent commercial laboratory. That they are kept remarkably clean is evident in the cleanliness of the film that they return to the owner after processing.

Despite their excellent facilities, significant differences occur among presumably similar laboratories; smaller, yet important, differences occur from week to week for the same laboratory; still smaller differences occur from day to day, and still smaller yet measurable and noticeable differences occur during a single day's run. The laboratory-to-laboratory differences can be observed by photographing a single test scene (with no change in view or other change during the scene), and sending a piece of this test scene to each of the laboratories in which you are interested. A single test does not mean very much, however, if the purpose is to accomplish control, since the magnitude and the character of the differences are, of course, independently variable.

Basic Functions of a Laboratory

Possibly the simplest way to determine what is needed in a laboratory is to trace the movement of film around a plant. The film is received in the *receiving department* where an entry is made in the plant records. The *planning department* determines just what shall be done and the manner in which it is to be done; this is scheduled in accordance with the order placed by the customer and by the needs of the film. The *preparation department* handles the film itself, and makes certain that all identifying marks needed to accomplish the required work are provided on the film and that it has the necessary leaders, etc.; this work closely follows the instructions of the planning department. The *developing department* develops the film; the instructions of the film owner and the supplementary instructions of the planning department usually specify in writing just how the film is to be developed. If the film handled in the preparation department was a negative or other film to be printed, the

preparation department provides the necessary printing marks and special instructions to the *printing department*. The printing department makes the copies as specified by the instructions of the planning department; should deviations from the normal procedure be required, the necessary instructions are provided by the *technical control department* which is responsible for technical coordination of the operation of the plant. If the film printed is black and white, it goes to the developing department where it is developed. After this, the film goes to the *inspection department* where it is inspected to make certain that the result specified by the planning department has been obtained. If all has gone well, the printed film then goes to the *shipping department* from which point it is sent to the customer.

If the laboratory has made a Kodachrome or AnscoColor dupe print —either silent or sound—it is shipped to one of the film manufacturer's laboratories for color developing. From there it is returned to the commercial laboratory for inspection prior to delivery to the customer.

Last but not least is the *accounting department* of the laboratory. The bills for the work accomplished are prepared from the data accumulated in the travels of the film through the plant.

Development

In almost all commercial laboratories, developing is done by machine; the laborious operations of developing by the rack-and-tank method are too slow and costly in terms of lack of uniformity of product and high labor costs. Recently (1953) Andre DeBrie began to market self-contained self-threading developing machines for 35 mm and 16 mm for about $5000. These are about the size of a 7 cu. ft. electric refrigerator and merely require connection to a hot water line, a cold water line, and an electric outlet. Quality is excellent; solutions are always fresh, as exhausted solution is not circulated back into the fresh solution.

For developing sound track at 6-min. developing time, the output of a Houston Model 22 machine would be less than 20 ft. per minute. Since film in the recording machine runs at a speed of 36 ft. per minute, it would take longer to develop a sound negative than it would to record it. The labor cost of developing film at this slow speed would be prohibitive for a commercial laboratory where present speeds range from a minimum of about 50 ft. to 200 or more ft. per minute. Needless to say, the length of a developing machine is approximately proportional to its operating speed; machines that run at 200 ft. per minute are usually more than 100

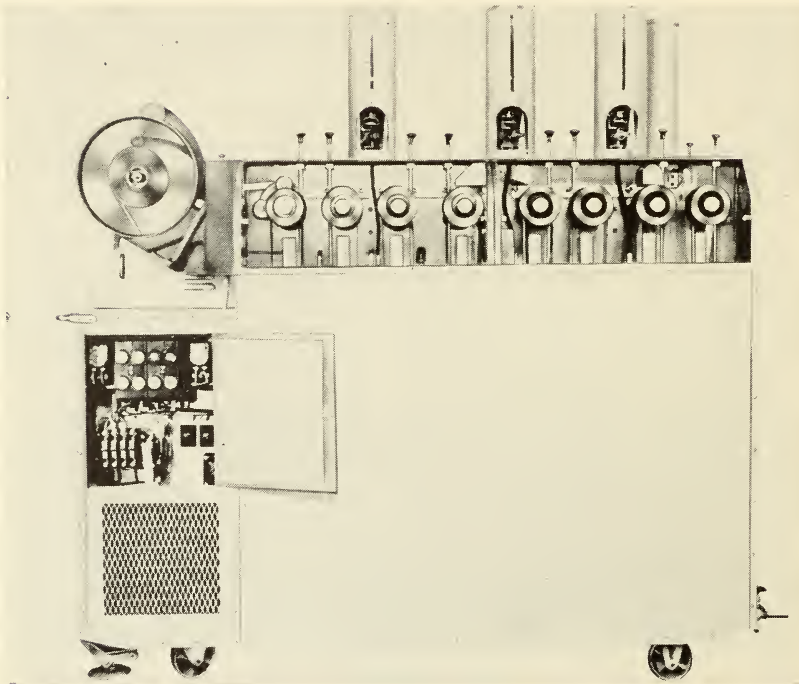


Fig. 91. Houston model 22 developing machine. Film travels from left to right in the foreground and reverses direction in the rear. Processed film is thereby taken up at the same end of the machine as that of loading. The overall dimensions are: length 76 in., width $26\frac{1}{4}$ in., height 66 in. The principal components are: ten tanks, drying cabinet, film driving mechanism (variable speed), two solution circulating pumps, an air compressor, a refrigeration system, a heater for the solutions, and 3 motors. There are infrared lamps for heating and a filter for cleaning the circulating air of the drybox. 1000 ft. magazines are provided so that the machine may be daylight operated, the magazines being loaded in a darkroom. For reversal processing see the table on the facing page.

ft. long and require over 1,000 ft. of leader to thread them from feed reel to takeup reel.

The Developing Machine

The usual developing machine is made in sections, the number of sections depending upon the purpose of the machine. A machine for developing positive is the simplest example; it has the shortest developing time and ordinarily runs at the highest speed. Its important sections (in sequence from head to tail of the machine) are (see Fig. 6):

Specifications and Reversal Processing Speeds for Houston Model 22 Developing Machine

Specifications

Tank No.	Function	Gallons	Ft in tank	Tank No.	Function	Gallons	Ft in tank
1	Loading elevator	Dry	20	6	Clear	4.5	26
2	First developer	9	52	7			
				7	Second developer	9	52
3	Wash	4.5	26	8	Stop bath	4.5	26
4	Bleach	9	52	9	Hypo	4.5	26
5	Wash	4.5	26	10	Wash dry-box	Running water	52

Total machine leader .... *505 ft.*

Reversal Processing Speeds

Film	Ft per min. machine speed	Film speed rating[a]	Film	Ft per min. machine speed	Film speed rating[a]
Dupont 301	8	50	Eastman Panatomic	20	32
Eastman XX	8	100	Dupont 314	25	32
Ansco Tri-SS	8	100	Eastman Super-X	25	32
Dupont 324	20	32	Dupont 330	32	32
Ansco Hypan	20	32			

Note: Developer formulas suitable for the various types are found in the operating instructions for the machines.

[a] When developed as recommended.

(*1*) A feed reel—where the film to be developed is placed on the feed hub of the machine.

(*2*) An "elevator"—where the length of the film loop between the feed reel and the developing tank is permitted to diminish when the feed reel is stopped for the purpose of putting on the next roll of film, the speed of the machine proper remaining constant so that developing time may remain constant. The length of the loop of film in the elevator decreases when the feed reel is stopped for reloading; it increases a predetermined amount at a predetermined rate when the feed reel is permitted to rotate again after loading, and runs at constant speed with the loop length unchanged after the predetermined loop length has been attained.

(*3*) The developing tank*—where the film is developed and the exposed emulsion "develops up," becoming dark in the process. The usual developer tank is one in which the film is completely submerged in the developer bath. Since development is more uniform and development rate (development gamma) is rapid with a high degree of agitation ("stirring"), various arrangements are used to increase developer agitation. Some of these arrangements include the circulation of developer in thin streams in the bath by introducing the developer at the bottom of the tank and removing developer at the top. Another arrangement introduces air jets at the bottom of the tank to increase agitation. In all cases the film passes alternately downward and upward in a developing tank; directional development effects (such as streaking caused by unidirectional flow of the developer past flow-disturbance-producing parts of the film, such as sprocket holes) are reduced.

Since the by-products of development tend to retard development and reduce development gamma, and since it is the very thin film of developer immediately adjacent to the surface of the film that effects development, it seemed reasonable to believe that a spray jet arrangement might be worked out that would require less developer solution, and yet develop the film in a manner more nearly approaching the theoretical optimum. Such an arrangement is in commercial use at DeLuxe Laboratories in New York where it was designed and built by E. Bertram. This machine is very economical of space; it provides a high rate of development without any measurable directional development effect and with a very high degree of uniformity. As the spray jet concept seemed fundamental from the viewpoint of theoretical hydraulics, the Bertram machine utilizes spray jets throughout rather than liquid immersion. Unfortunately, no description of the machine or of its operation has been published despite the fact that the machine has been in commercial use for several years.

(*4*) The wash tank—where traces of the developing solution remaining on the film are washed away with water prior to the entry of the film into the hypo tank. Oftentimes there is an air squeegee for removing excess developer solution from the surface of the film before it enters the wash tank. A squeegee is a means of removing excess water or liquid; it usually consists of two blasts of air, one on each side of the film, to blow off the excess liquid. The film is usually completely submerged in water during its passage through the wash tank; it emerges between tanks.

(*5*) The hypo and the hardener tank—where unexposed emulsion is "cleared" from the film and where formaldehyde or other emulsion-hardening chemicals may be added to the hypo bath if desired.

(*6*) Another wash tank—to remove traces of the fix bath.

(*7*) The first stage drybox—where the film, after passing a squeegee, is slowly and partially dried by a steady blast of warm dry air which is usually fed into the bottom of the first-stage drybox and exhausted from the top. The squeegee is especially important at this point, since the film would be badly water-streaked if the water were

* Eastman Kodak and Dupont have been evolving film emulsions suitable for high-temperature processing. Recent types of emulsion can be developed as a negative in less than half a minute; the development time for a comparable commercial emulsion would be about 15 minutes. It is well known that the chemical activity of substances increases rapidly with increase in temperature, and it is indeed a portent of things to come in the near future to find that the development time has been reduced to such a great degree and yet development fog and graininess have been retarded so materially.

permitted to dry without it. Usually there is a flannel-covered roller rotating within the cabinet against which the base side of the film gently rides as it goes through; this is known as a polishing roller.

(*8*) The second stage drybox—where the film is slowly and finally dried by a steady blast of warm air that is cooler than the air in the first stage. The second-stage drybox may be more than twice as long as the first-stage drybox. Film is dried best if the surface is not dried too rapidly with respect to the rate of diffusion of the moisture from the inside of the film to the outside. Moisture diffuses quite slowly from inside to outside compared with surface evaporation under common drying conditions.

Theoretically, the drying air temperature should be a maximum where the film enters the drybox, and should drop to approximately ambient air temperature. Staging is a practical means of accomplishing the objective.

Drying is a very important function, and many commercial machines dry both improperly and insufficiently. The common error is to apply air that is too hot for too short a time, leaving the surface excessively dried and the body of the film with an excessive moisture content. After such a film is removed from the developing machine, the internal moisture diffuses to the surface making it sticky. Such a film is known in the trade as ''green film.'' The physical distortions suffered by the minute picture and sound images can be imagined when it is realized that the thermal coefficient of linear expansion of the emulsion is some 8 times that of the film base.

The Research Council of the Academy of Motion Picture Arts and Sciences of Hollywood issued a Technical Bulletin ''Report on Film Preservative Tests'' (Apr. 14, 1939) that described green film and the subsequent treatment it sometimes receives to counteract it:

> ''Treatment given to release-print film after it has been printed, developed, and dried is commonly called 'film preserving,' and the processes by which this treatment is given are known as 'film preservative' processes.
>
> ''The gelatin of freshly developed film carries a high percentage of moisture in its pores and as long as this condition prevails is known as a 'green' emulsion. A so-called 'green' emulsion is quite soft and the slightest abrasion will cause a scratch. These scratches widen out as the gelatin dries, and cause the 'rainy' effects occasionally seen on the screen in the theater when old films are run.
>
> ''As film with 'green' or soft emulsion passes through a projector, it leaves small deposits of emulsion on the tension shoes at either the aperture plate or the sound-gates, unless the tension shoes are kept thoroughly lubricated. Such deposits build up resistance to free passage of the film over them, and scratch the film during projection.
>
> ''When the moisture in a 'green' emulsion is withdrawn too quickly, the gelatin shrinks and the film warps or buckles. If too great an amount of moisture is withdrawn from the gelatin, the film becomes brittle, loses its pliability, and is easily torn while being projected.''

The subject of ''green'' film is usually considered ''delicate''; it is too often explained away rather than investigated and corrected. Many film preservative processes are to some extent processes that attempt to correct improper drying by other means such as emulsion hardening. Such processes do not correct improper drying; the treated film would be even better if the film were dried properly. Oftentimes ''film preservatives'' are applied a day or two after the film has been developed,

giving the film an opportunity to become moisture-stabilized and to dry further before the emulsion hardening (which reduces moisture exchange with the atmosphere) takes place. Generally speaking, the drybox of the developing machine should be several times as long as the developing tank—the longer, the better.

(*9*) The tail-end takeup elevator—where the length of the loop between the last drybox and the tail-end takeup is permited to vary in a manner similar to that of head-end elevator to allow for the periodic removal of filled reels from the machine.

(*10*) The tail-end takeup—where the film winds up for removal from the machine. Some developing machines have some film protective or preservative treatment applied in a developing machine section located between the last drybox and the tail-end takeup elevator. Edge-waxing is one form of treatment applied; the purpose of edge-waxing is to reduce friction between the film and the film gate of a projector.

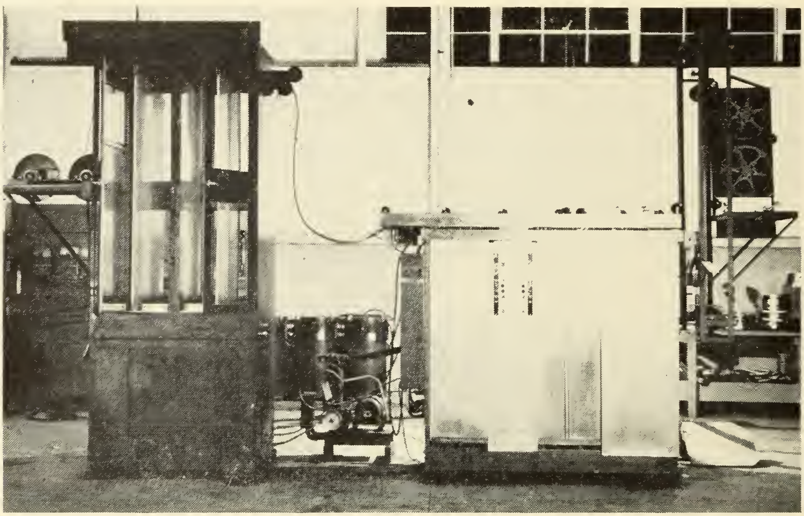


Fig. 92. Fonda F-1011 positive developing machine. This is a typical commercial machine for developing 16-mm positive film. *Normal speed:* 65 ft per min. at 4 min. development (commercially satisfactory at 87 ft. per min. with 3 min. developing time). *Total machine leader:* 2800 ft. (approx.). *Feet in developer tank:* 260. *Feet in hypo tank:* 475. *Feet in drybox:* 1325. *Quantity developer:* For circulating developer—80 gals when mix tank is not used in circulating system, 160 gals when mix tank is used. *Wash water:* 17 gals per hour (spray wash). *Floor space:* 16 ft by 3 ft by 12 ft (high). *Price:* Between $15,000 and $20,000. As scheduled, the drybox has no elevator, and hypo circulation pumps are not provided.

Developing machines vary widely in size, design, space requirements, capacity, and price. Very small machines are not generally suitable for commercial operation in commercial film laboratories because of their low operating speeds. It has been found that the amount of labor

required for operating a large developing machine is but little more than that for a small one. All indications point to greater competitive advantage in high-capacity machines. For general commercial 16-mm film laboratory operation on even a modest scale, a machine speed less than of about 50 ft. per minute for positive film developed at 3-min. developing time will not be more than marginally competitive in the larger cities

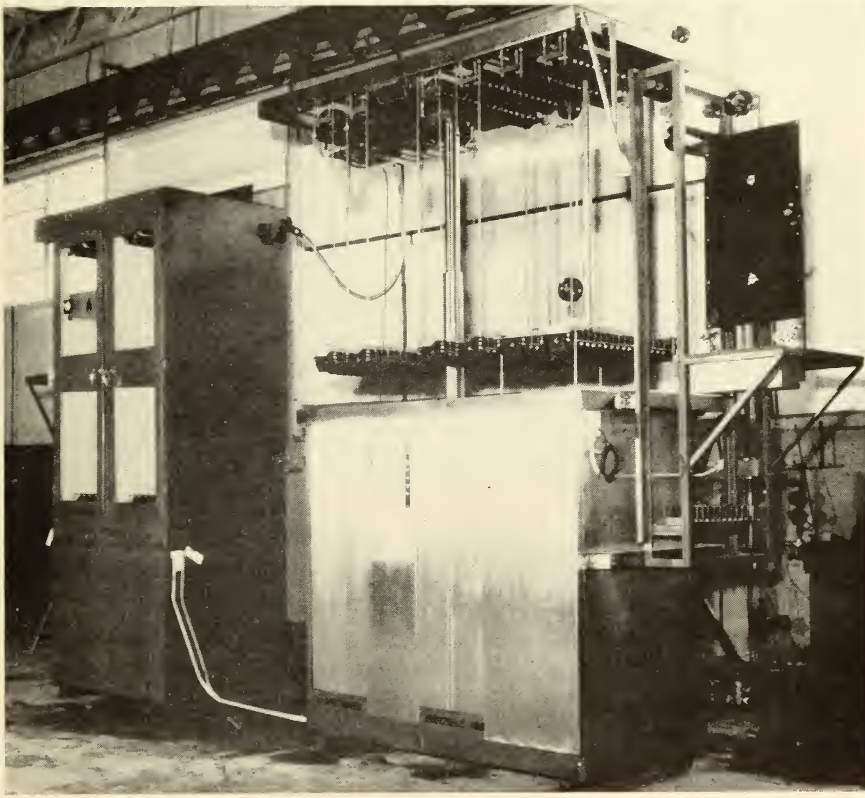


Fig. 92A. Film driving rack of Fonda machine, elevated to permit inspection and cleaning.

of the United States despite good technological and business management. Figures 92 and 92A show a Fonda positive machine rated at 65 ft. per minute at 4 minutes development time.

Modern machines are built in sections, permitting some "standardization" of tanks and other parts. With such standardization, the benefits of cost reduction that attend quantity production and interchangeability

of parts make for flexibility of machine design as well as lower cost. Thus, if a machine were to be altered to provide a development time of 6 minutes (*e.g.*, for sound track originals), it would be necessary to add but one developing tank to a machine that is operating satisfactorily at a development time of 3 minutes when used for release prints. Thus, the output of the machine in feet of film per hour would be the same when developing 6-min. sound film as it is in developing 3-min. release prints. Without the extra tank, it would be necessary to reduce the machine speed to one-half, thereby reducing its film output per unit time to one-half.

In general, machine drive is of two kinds: friction and sprocket. Different makes of film ''stretch'' different amounts when wet with solution; the increase in length is quite large (it may be as large as 0.5%). ''Overdrive'' is provided in the case of friction-driven machines; it is important that the machine compensate automatically for the increase in the desired amount. In the case of sprocket drive, the sprockets used must be designed for the proper ''stretch'' and for the proper shrinkage ranges. Fortunately, there has been great improvement in the dimensional stability of films and smaller dimensional change during development and there is promise for still better stability in the films of the future. At present, most catalog developing machines offered for sale are of the friction-drive type.

Developing

It is impracticable in a single chapter to cover the many important factors in developing machine design or operation. Suffice it to say that among positive developer baths the Eastman D-16 is widely used although in a variety of concentrations and with minor variations that depend upon specific conditions of use and, in too many cases, upon the whim of the man in charge. A developer bath usually consists of:

(*1*) Reducing agents—Elon, Metol, Hydroquinone, Paraphenylenediamine, Glycin, Pyrogallate, and others. Metol (monomethylparaaminophenol sulfate) is sold under a variety of trade names; these include Rhodol and Pictol. The reducing agent reduces the exposed emulsion to metallic silver without affecting the unexposed emulsion.

(*2*) An alkali—sodium carbonate. This is needed because most developing agents are relatively inactive except in alkaline solution. In addition, the alkali aids in swelling the gelatin to permit action by the reducing agent upon the emulsion.

(*3*) A preservative—sodium sulfite or potassium metabisulfite. This is used to prevent oxidation of the reducing agents.

(*4*) A restrainer—potassium bromide. This is used to restrain very active solutions from reducing unexposed as well as exposed emulsion.

(*5*) A solvent—water.

The developer bath is rapidly circulated through the machine by pumps; temperatures of developer and fixing baths are usually controlled within ± 0.25° F. Ordinarily, a fairly large storage tank is used as a reservoir; the bath is circulated from the tank through the machine and back to the tank. The flow of fluid in the machine is opposite to the direction of travel of the film where practicable. Fluid usually enters the developer tank at the bottom and overflows at the top, returning to the storage tank.

Fixing

A fixing bath is an acid hardening bath that "clears" the film of unexposed emulsion. The principal constituent is hypo (sodium thiosulfate)—the clearing agent. For proper action in fixing and hardening, the time allowed for the fixing bath should not be less than twice the time just necessary to clear the film.

Hardeners are usually chrome alum or potassium alum. The hardening agent chosen depends upon the degree of hardening desired. To prevent precipitation of free sulfur which occurs in acid solution, sodium sulfite is added. The acids in the bath are usually acetic acid and boric acid.

Published Formulas. Photographic chemicals cannot tolerate certain impurities common in U.S.P. chemicals. It is necessary to make certain that the chemicals purchased are of photographic grade* to avoid difficulties that arise from such impurities. Table XX lists common solution formulas.

For release prints, little variation in the Eastman D-16 formula (except possibly for concentration) is ordinarily justified. There may be a change in the balance between the Elon and the Hydroquinone, but in relatively few cases are the changes significant.

For the development of negative, however, changes in the bath from the Eastman D-76 reference bath listed are very common. Many such changes show significant improvement in picture quality or in "adjusting the bath to the machine" with regard to middle-range machine de-

* Specifications for chemicals of photographic grade may be obtained from the American Standards Association, 70 E. 45 St., New York, N. Y.; there is a specification for each of the many common photographic chemicals, including all those listed in the above formulas.

veloping time. As has been pointed out in Chapter III, the graininess characteristics of the release print depend to a very material degree upon

TABLE XX
Single-Solution Processing (Positive or Negative)
(Eastman Kodak)

Positive bath (EK D–16) for picture, VA track, and release prints		Negative bath (EK D–76) for picture	
Water (125° F.)	90 gal.	Water (125° F.)	90 gal.
Elon	4 3/4 oz.	Elon	2 lb.
Sodium sulfite (desiccated)	38 lb.	Sodium sulfite (desiccated)	100 lb.
Hydroquionone	6 lb.	Hydroquinone	5 lb.
Sodium carbonate (desiccated)	19 lb.	Borax (granular)	2 lb.
Potassium bromide	14½ oz.	*Water to make 120 gals.*	
Citric acid	11¼ oz.		
Potassium metabisulfite	1 lb. 6½ oz.		
Cold water to make 120 gals.			

Negative bath (EK D–103) for VD track (small-scale development)		Fixing bath (EK F–25)	
Water (125° F.)	90 gal.	Water (125° F.)	60 gal.
Elon	2 lb.	Hypo	300 lb.
Sodium sulfite (desiccated)	100 lb.	Sodium sulfite (desiccated)	5 lb.
Hydroquinone	5 lb.	Acetic acid (glacial)	1 gal. 22 oz.
Borax (granular)	1 lb.	Boric acid (crystals)	5 lb.
Boric acid (crystals)	15 lb.	Potassium alum	10 lb.
Potassium bromide	2 oz.	*Water to make 120 gals.*	
Water to make 120 gals.			

Gevaert GD–190 (high contrast—long life)[a]	
Water (about 52° C.)	2000 cc
Potassium metabisulfite	30 g.
Sodium sulfite (anhydrous)	120 g.
Hydroquinone	90 g.
Sodium carbonate (monohydrate)	240 g.
Citric acid (crystals)	5 g.
Potassium bromide	12 g.
Water to make	*4000 cc*

Time of development: 4 to 5 minutes at 68° F.

[a] Possible alternate for EK D-76 (above) in event that Metol fog is undesirable.

negative development, whether it be dupe negative or original negative. Glycin developer baths with relatively short developing times (about 4

minutes) have been quite advantageous with EK 5203 dupe negative film for making intermediate dupe negatives between the original reversal and the fine-grain release print. Other reducing agents also will be found advantageous. Graininess is reduced materially by selecting the right kind of developer bath and by reducing the developing time (with compensating increase of dupe negative exposure) thereby taking advantage of the difference between the graininess – developing time characteristics of negatives and positives. There is still much to be done in reducing the graininess of release prints; the dupe negative will provide much of the opportunity.

Two Solution (Reversal) Processing

For reversal developing, a few more processing steps must be added. A typical procedure would be:

1. A pre-hardener
2. A developer
3. A water rinse
4. A bleach
5. A clearing bath
6. A second exposure—provided by a relatively bright lamp (not controlled)
7. A second developer
8. A water rinse
9. A fixing bath
10. A wash
11. Drybox

Typical formulas used are listed in Table XXI.

The fixing bath (9) may be the same as that used with negative or positive development; the EK F-25 bath listed previously is suitable.

As a practical matter, laboratories that can afford to do so use separate developing machines for the different kinds of processing. Where this is not possible the developer and the hypo (or other chemicals such as those used for reversal development) are pumped out of the machine to storage tanks for future use. The machine is then cleaned out and the different developer or other chemicals pumped in. The practicability of this method depends upon the design of the machine itself. The problem of draining is similar to that of draining an automobile radiator. If the drain is not at the lowest point in the system with sufficient grade to cause

TABLE XXI
Two-Solution Formulas

Pre-hardener (1)	
Water	6 gal.
Calgon	0.5 oz.
Sodium bisulfite	3 oz., 80 gr.
Sodium sulfate (anhyd.)	3 lb. 5.5 oz.
Sodium carbonate (anhyd.)	4.5 oz., 24 gr.
Paraformaldehyde	4 oz., 120 gr.
6-Nitrobenzimidazole nitrate (0.5% solution)	5 fl. oz., 4 fl. dr.
First Developer (2)	
Water	3 gal.
Calgon	0.5 oz., 130 gr.
Metol	1 oz.
Sodium sulfite (anhyd.)	5 lb.
Hydroquinone	2 lb.
Potassium bromide	12.5 oz., 140 gr.
Sodium thiocyanate	4 oz.
Sodium hydroxide	2 lb.
Water to 12 gal.	
Bleach (4)	
Water	6 gal.
Potassium bichromate	12 oz.
Sulfuric acid	18.5 fl. oz.
Water to 8 gal.	
Clearing Bath (5)	
Water	4 gal.
Calgon	146 gr.
Sodium sulfite (anhyd.)	3 lb.
Water to 5 gal.	
Second Developer (7)	
Water	10 gal.
Calgon	0.5 oz., 130 gr.
Metol	1.5 oz.
Sodium sulfite (anhyd.)	5 lb.
Hydroquinone	2 lb.
Potassium bromide	8 oz.
Sodium hydroxide	1.5 lb.
Water to 12 gal.	

DuPont 314, Eastman Super X (5256) and Eastman Super XX (5261) can be processed like Universal films in the above baths. For Ansco Hypan Reversal, Triple-S Reversal, and DuPont 301, add sodium thiocyanate to the first developer. The black nonhalation silver backing on Eastman Super X (5256) and Super XX (5261) may be removed by a sponge in the first developer tank.

thorough draining to that point, contamination of the newly pumped developer occurs. This is undesirable, since it may result in an undesirable increase in graininess or in other characteristic that cannot be corrected by merely changing the speed of the machine.

In general, the bath that is richest in reducing agents (such as those listed) provides the best photographic quality. To a great degree developing is a matter of how much one can afford to spend on the reducing agents used in the bath. Although increasing the alkali and decreasing the reducing agents in a bath may produce like development contrasts, the major penality is a marked increase in graininess. The price of alkalis is but a fraction of a dollar per pound, whereas reducing agents cost several dollars per pound, and it is not uncommon to find developer baths in commercial laboratories using excess alkali and insufficient reducing agents.*

Printing: The Printer

A printer has been defined as a machine that forms a latent image in the photographic emulsion of raw film with light modulated by an image carried on a separate film. Printers may be classified in accordance with the relationship of the two emulsions concerned: (*1*) contact—where the emulsion of the film to be copied and the emulsion of the raw stock are in intimate physical contact, and (*2*) projection—where the image of the film to be copied is projected by suitable optical means upon the emulsion of the raw stock. Projection printers may be classed as: (*a*) enlarging—where the projected image is larger than the image on the film to be copied; (*b*) reducing—where the projected image is smaller than the image on the film to be copied; and (*c*) one-to-one—where the projected image is of the same size as the image on the film to be copied.

A printer requires (*1*) a light source—often an incandescent lamp, (*2*) a printer gate or aperture—the portion of the machine where the image is transferred, (*3*) a light control—this may be an iris diaphragm similar to that used with a camera lens or other aperture control and/or it may be a rheostat connected in the lamp circuit for suitably dimming the lamp, (*4*) a motor—usually a synchronous a.-c. motor to avoid changes of speed resulting from slight changes of mechanical load, (*5*) feed and takeup reel arms—for accommodating both the film to be copied and the

* For details as to solution mixing procedure, etc., the reader is referred to *Photographic Chemicals and Solutions* by Crabtree and Matthews (American Photographic Publishing Company, 1939).

raw stock upon which the copy is to be made, and (*6*) a frame (usually a casting)—for mounting all the equipment and parts needed.

Picture Printers: Continuous Contact Printer. The continuous contact printer is one of the most common in commercial use. It moves the two films in intimate physical contact at uniform velocity past the printing gate, where the raw stock is exposed to the light from the printer lamp that is "modulated" by the image on the film to be copied. (The sequence of parts is: light source, printer sprocket supporting the image-bearing film with its emulsion facing away from the lamp, raw stock with its emulsion facing the emulsion of the image-bearing film; gate closure which supports the gate shoes that press the raw stock against the image-bearing film by means of springs.)

Printing usually takes place at the periphery of a large printing sprocket that propels the films together past the printing gate; it is this printer type that is capable of operating at high speed. A common speed for a 16-mm printer of this type (such as the Depue, Fig. 93) is about 60 ft. per minute; 35-mm printers are in use that run at speeds well over 200 ft. per minute. As the speed is increased, it becomes increasingly difficult to maintain good contact between the films being printed. Continuous contact printers are used for release printing where some sacrifice in resolving power can be made for the sake of high running speed and correspondingly lower print price. The prime disadvantage of the continuous contact printer is that a loss of at least 30% in resolving power occurs with even the best construction possible; poorer constructions result in still higher losses.

As the speed of printing increases, it becomes increasingly difficult to effect light changes. These are changes in illumination that are required to correct for the undesired density variations in an image-bearing film being copied. There are two general methods of light-changing used with such printers: (*1*) a change in lamp brightness—usually effected by a rheostat in the lamp circuit of an incandescent lamp, and (*2*) a change in the aperture or diaphragm in the illumination system, the change in illumination being proportional to the change in area of the diaphragm or aperture. There is appreciable thermal lag in an incandescent lamp filament; for example, a printer operating at 20 ft. per minute that uses a 500-w. lamp as a light source will require about 4 or 5 printed frames to complete a change of brightness of 50% when the change is made with a rheostat. Mechanical systems of light change that

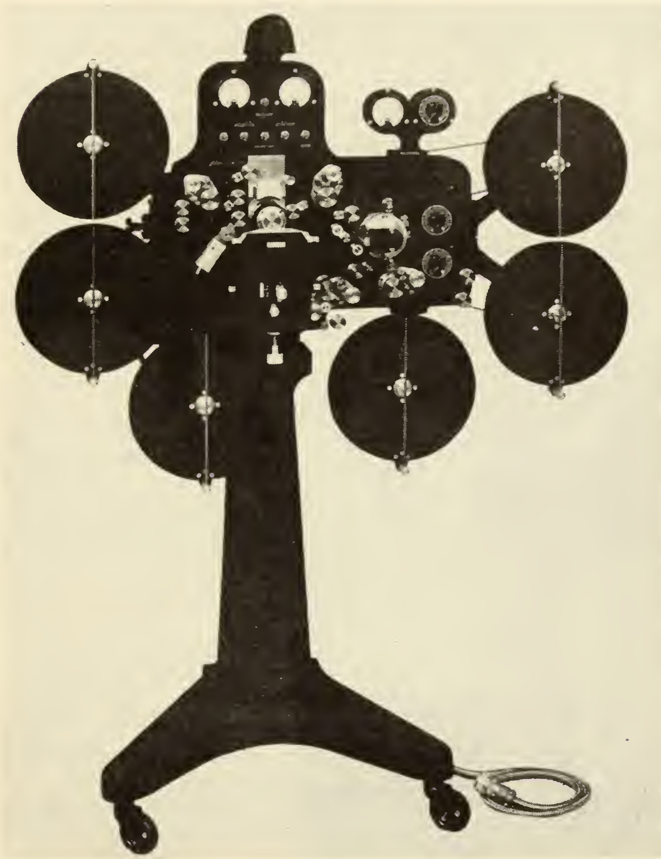


Fig. 93. Depue double head continuous contact combination 16-mm printer. This machine can print one combination print from separate picture and sound pre-print films. This is accomplished by providing two printing heads, one for the picture and one for the sound. Printing speed is in the range from 60 to 110 ft. per min., the lower speed being required for films requiring high exposure levels. The picture printing lamp is rated at 100 watts (projection type used at line voltage), and the sound printing lamp is rated at 115 volts, 25 watts (tubular type). A separate 25-watt lamp with its rheostat is provided for printing edge numbers. All hubs designed to hold a maximum of 1200 ft. For printing Kodachrome, the color temperature of the 100-watt lamp is ordinarily too low; provision is made for substituting a 10-volt 7.5-ampere exciter lamp for picture printing. Like most conventional printers, this machine runs in one direction only.

effect control by means of a change in area of an aperture or diaphragm often have appreciable inertia, and the mass in the mechanism must be moved quickly to effect the change. With certain arrangements it is difficult if not impossible to effect the change completely between two adjacent printed frames. Where quantity prints are to be made with scene density changes at high speed, a traveling matte may be used. This is merely a film interposed at the gate between the light source and the image-bearing film that alters the light intensity in the manner of a

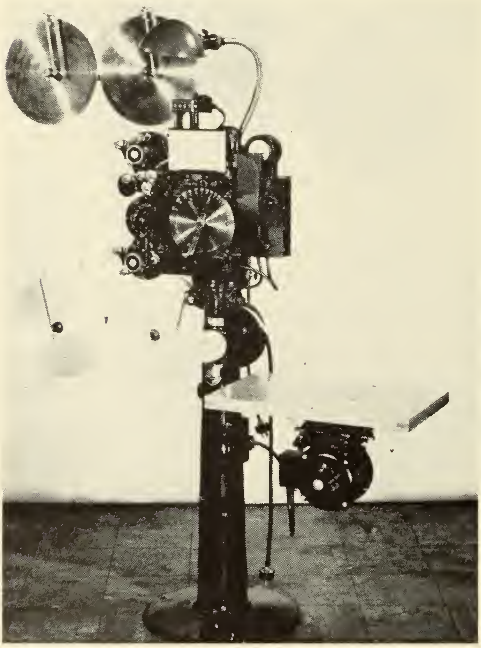


Fig. 94. Bell and Howell, model J, 16-mm combination printer. Adjustable width aperture is used to effect changes in print exposure. It has a single printing head and lamp with separate apertures for picture and for sound printing. Can make a silent picture print or a sound print in a single trip through the printer; it can also make a combination print from a combination negative. To make a combination print from separate picture and sound negatives requires two trips of the raw stock through the printer; one trip to print picture, and the other to print sound.

neutral density filter. Traveling mattes are rarely used in 16-mm release printing; it is more practicable to make the timing corrections in the dupe negative in such manner that the release prints may be printed at a single printer light setting.

Typical commercial printers available are the Bell and Howell Model J (Fig. 94) and the Depue Combination. The Depue (Fig. 93) has the advantage that it provides three sets of feed and takeup reel arms, one for accommodating the picture image-bearing film, the second for accommodating the sound image-bearing film, and the third for accommodating the raw stock to be printed; a combination print may be made

from separate picture and sound films in a single trip through the printer. As may be expected, there is a wide range of performance of continuous printers both in regard to picture and sound quality and in regard to price. Continuous contact printers must be checked regularly to make certain that proper contact is maintained and that they do not introduce excessive flutter into printed sound. This latter can be done by making test prints periodically, using an SMPE flutter test film ASA Z22.43 or its equivalent as the film to be copied. The SMPE test film is then compared with the test print by running the films on a film phonograph and observing the wave form of first one and then the other as seen on a cathode ray oscillograph. Tests for picture contact can be made by making periodic test prints of film bearing resolving-power test charts and viewing the tests by projecting them.

Step-Contact Printer. Another type of picture printer in common use is the step-contact printer. In this machine, the film, instead of moving past the film gate at uniform velocity, moves into and out of the gate with an intermittent motion similar to that of a camera. Just as with the camera, a shutter cuts off the light from the light source during the interval that the film is being moved from one frame to the next. Because the film is stationary in the aperture during the exposure interval, the quality loss (measured as resolving power loss) is usually measurably less than that of a continuous contact printer. Common operating speeds of such printers are often about 20 ft. per minute; some of the newer machines have the speed increased to 60 ft. per minute. Most good printers of this type have some form of gate pressure control that automatically applies appreciable pressure to the films to improve their contact during the exposure interval; the pressure is released during the interval when the film is being moved. With machines maintained in best order, the step-contact printer is a "standard of comparison" by which the performance of other printers may be judged. The quality should approximate very closely the "ideal" of a printing frame used for still pictures. Test prints in a still picture contact printing frame can be made for comparison; ASA Z38.7.10-1944 and Z38.7.11-1944 and related specifications provide test information and methods.

Although many equipment manufacturers have marketed step-contact printers from time to time, DeBrie (France) has been the most consistent manufacturer of this type of machine. Earlier machines (before World War II) were equipped with rheostat-type light changers; newer

machines (Fig. 95), after World War II, are equipped with an aperture form of light changer that is simple, yet a bit unusual. A strip of fiber

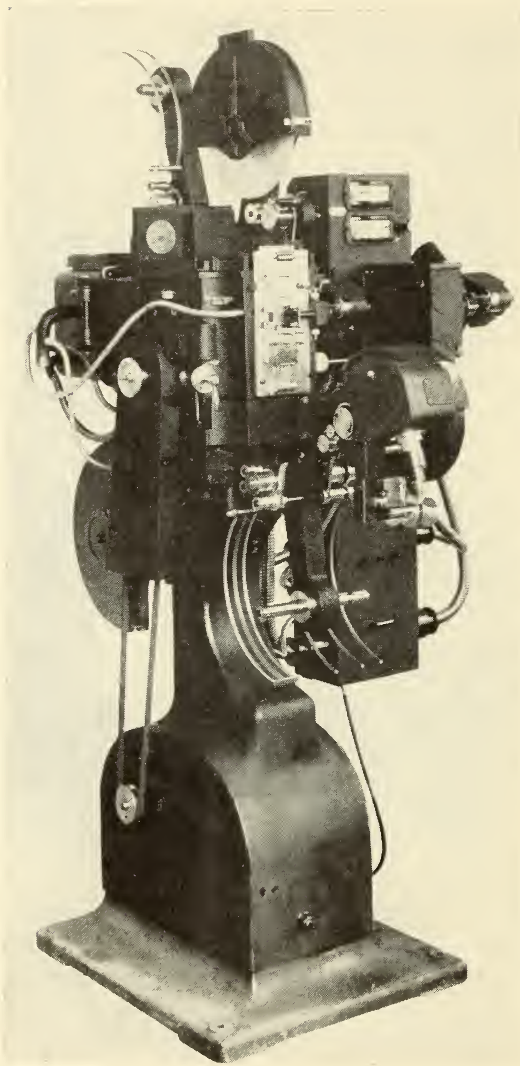


Fig. 95. DeBrie printer. Can make two 16-mm prints simultaneously on 16-mm films by optical reduction from one 35-mm picture negative and its 35-mm sound track negative. By replacing the interchangable aperture plate, the machine may be quickly modified to print 16-mm step-contact picture. The light path when used as such a printer is shown in Figure 96. The light change strip for the machine is shown in Figure 104. The machine speed is 26 ft. per minute; when used as a twin printer, the output is 52 ft. of 16-mm prints per minute.

35 mm in width is interposed in the illumination system between the lamp and the film gate; the strip is pre-perforated with holes of such diameter as to alter the printing illumination in the desired manner. The strip

moves from one hole to the next while the film is being moved from one frame to the next at the point where a change in printing illumination is desired. The change occurs during the time when the shutter is closed between frames; there is no change in lamp output in the interim.

Fig. 96. Schematic of light path in DeBrie step contact printer. The light change strip shown in Figure 104 may be used to transport a filter holder with special filters for color correction of individual scenes when the machine is used for color printing. (See Figs. 95 and 104.)

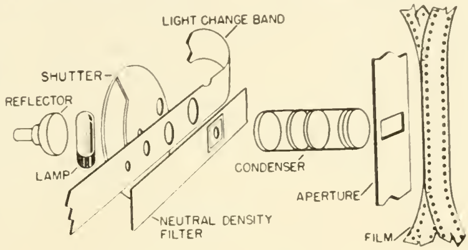


TABLE OF PICTURE ILLUMINATION
(Printing Lamp Rheostat Set at 108 Volts)

Light change band hole number	Light change band hole size		Foot candles	Lux
	Inches	Mm		
20	0.710	18.00	4180	45,000
19	0.603	15.30	3740	40,200
18	0.567	14.40	3335	35,900
17	0.530	13.45	2970	32,000
16	0.496	12.6	2660	28,600
15	0.482	12.25	2370	25,500
14	0.443	11.25	2120	22,800
13	0.418	10.60	1892	20,400
12	0.402	10.20	1690	18,200
11	0.382	9.70	1506	16,200
10	0.362	9.20	1347	14,500
9	0.335	8.50	1200	12,900
8	0.311	7.90	1072	11,550
7	0.299	7.60	958	10,300
6	0.290	7.35	855	9,200
5	0.272	6.90	762	8,200
4	0.260	6.60	683	7,350
3	0.248	6.30	608	6,550
2	0.236	6.00	543	5,850
1	0.224	5.70	485	5,220

Figure 96 is a schematic of the light path. This arrangement is convenient for the printing of integral tripack color films where changes in the color balance of particular scenes are desired.

The latest DeBrie step contact printer is a three-color additive machine

deriving its green, red and blue components from a single light source. A triple photographic grating with 40 steps for each color attenuates each component individually; 64,000 colors are thus available.

Projection Printer (Optical: One-to-One). The projection printer is one that projects an image from the image-bearing film to be copied to the emulsion surface of the raw stock upon which the exposure is to be made. There are two separate film gates in this printer, one for the image-bearing film, and the other for the raw stock. Both films are moved simultaneously by claw movements that are geared to function together and to cause the two films to move in like manner.

A light source—usually an incandescent lamp—is used with an appropriate condensing lens system to illuminate the image-bearing film that is located in one of the two printer gates. A high-quality projection objective lens focuses the illuminated image upon the emulsion surface of the raw stock located in the second film gate. A shutter admits light through the optical system when the films are stationary in their respective gates; the shutter cuts off the light while the films are moving between exposures. The shutter action is quite like that of a camera.

A typical commercial printer of this type that has been on the market for some time is the Bell and Howell; this has a top speed of 18 ft. per minute. There have been numerous designs evolved in recent years, mostly directed to increasing running speed, and to providing special features to facilitate the printing of integral tri-pack color films such as Kodachrome. Such features include the making of fades, wipes, dissolves, and other effects while the print is being made, and the correction of color balance and of scene density from scene to scene where required. Several organizations have constructed or are constructing a small number of printers of this general type for their own use or for the use of affiliated film laboratories. In many cases the printer has been set up to provide a "standard" emulsion position print from a "standard" emulsion position original. The poor quality of sound heard in the loudspeaker of an ordinary 16-mm sound projector (set up—as most are—for the projection of "standard" emulsion position prints only) has been an incentive quite as much as the need for re-focusing the picture on a projector when "non-standard" emulsion position films are to be shown. Many printers such as the Acme (Hollywood) are designed to provide automatic fades in the printer of the more-or-less accepted lengths of 40 or 48 frames; some are able to provide fades of any length that may be desired.

An optical printer is difficult to adjust, to maintain and to keep in adjustment, and to keep clean. It is quite expensive if the optics are really good; it is not worthwhile if the optics are not good. An optical printer should have a coated main objective lens of relative aperture preferably not narrower than $f/2.0$; it should be well corrected both geometrically and chromatically, and have resolving power all over its field of not less than 100 lines per millimeter. Such lenses are rare in appropriate focal lengths. Should they become more plentiful later on, it is unlikely that they will be low in price. Special lenses have been manufactured that are excellent, but very few suitable lenses are manufactured as stock items or catalog items.

The first cost and the operating costs of a good projection printer are quite high compared with contact types of printers. Operating costs will have to be cut by increasing machine speeds and by improving machine control, and possibly first cost reduced materially before this class of printer comes into universal use. For such reasons it is likely that the less costly types will continue in use for some time despite their somewhat inferior picture quality when compared with a very good—and expensive—projection printer.

Sound Printer (Contact)

All sound printers are continuous printers, the films moving at constant velocity. The most common form of sound printer is the contact printer, which is the same as the continuous contact printer used for picture, with the exception that the printing aperture limits the light-causing exposure to the sound area rather than to the picture area. Continuous contact printers such as the Bell and Howell Model J use a shutter arrangement that is made of two portions, one for shutting off or admitting printing light to the picture area, and the other for similar control of light to the sound track area. Both may be opened at the same time if desired, to make a combination print from a combination negative. The area of the aperture formed by the shutter is altered to effect changes in exposure of the copy being made.

Imperfect contact in such a printer gives rise to a loss of resolving power; the most noticeable effect is a loss of high frequencies. Unfortunately, this loss is not constant; it varies more or less regularly with the approach and departure of each of the sprocket teeth that propel the films. When film speed is high, a layer of air may become trapped between the image-bearing film and the raw stock, giving rise to a separa-

tion of the films, and reducing the effectiveness of the contact. This separation varies, since the trapped air alternately "leaks out" and becomes trapped.

A critical feature in the design of contact printers of the continuous type is the design of the printing sprocket. This is designed for a specific shrinkage relationship between the image-bearing film and the raw stock. Since the image-bearing film is relatively old and shrunk to a greater degree than the relatively new raw stock, its actual length per 100-sprocket-hole interval is shorter. The difference in length between

Fig. 97. Maurer 16-mm shrinkage gauge.

the image-bearing film and the raw stock is accounted for by the diameter of the printing sprocket and the pitch of its teeth. In the "ideal" case, the difference in length is exactly accounted for by the difference between the smaller mean diameter of the image-bearing film and the larger mean diameter of the raw stock as the films are curved about the sprocket. When engaged, the sprocket teeth in this "ideal" case can locate in the exact center of the sprocket holes of both films. Another consideration in the design of the sprocket is the range of shrinkage that the sprocket is designed to accommodate. Since the shrinkage of 16-mm films has been

continually reduced during recent years, sprockets of older machines (*e.g.*, 10 years old) will be found to have improper dimensions for printing present-day films. When continuous contact printers are used for printing, and excessive flutter is observed, it is advantageous to have available a 16-mm shrinkage gage (Fig. 97) so that the shrinkage of the films involved can be measured accurately and quickly. If unusual conditions are encountered, the manufacturer of the printer may be able to supply special sprockets to fit special shrinkage conditions. Actual data are important in choosing a sprocket design that more closely approximates actual conditions of use.

The newer films as now manufactured have appreciably improved dimensional stability, with the result that in many cases the image-bearing film is not sufficiently shorter than the raw stock to fit properly on the sprocket; with older films, the reverse is often true. As the "ideal" conditions mentioned are not ordinarily realized in practice, some flutter is bound to occur. This condition will be noticeable to a keen observer on the better grade sound projectors and may be noticeable to the average observer on a high-quality system consisting of a film phonograph, high-quality amplifier, and two-way loudspeaker system.

Flutter refers to any deviation of amplitude and frequency resulting from irregular motion in the recording, duplication, or reproduction of a tone. The term also includes any such deviation that arises from deformation of the record material. The flutter content of films made upon modern sound-recording machines is quite low, and most of the flutter found in release prints is introduced by sound printers, usually of the continuous-contact type. The flutter introduced is usually caused by the alternate acceleration and deceleration of one film with respect to the other during the engagement, driving, and disengagement cycle for each sprocket tooth of the drive sprocket. For this reason the predominant flutter frequency in direct 16-mm film is likely to be 24 per second; in sound film optically reduced from 35-mm, the predominant flutter frequency is likely to be 96 per second (see Proposed ASA Z24.1-1949).

Non-slip Printer. The non-slip printer is a special form of continuous contact printer that is designed to avoid the introduction of flutter by making the printing exposure on a free-floating or other mechanically-filtered drum in much the same manner as a sound-recording machine. The non-slip printer was first introduced for printing 35-mm film; it was quite successful in materially reducing 35-mm print flutter. Sample 16-mm printers of this type that were built and studied about a decade ago by one manufacturer failed to show a significant improvement in 16-mm print performance; the increased cost of the printer did not seem to be justified. Since then other non-slip printers have been manufactured by

other organizations; although the performance of projectors with regard to flutter has been materially improved, there is still no consensus of opinion in favor of non-slip printers for 16-mm. Figure 98 is a sketch of the film path for a non-slip printer.

Optical One-to-One Sound Printer. In an attempt to reduce the losses in sound printing and to improve film motion to minimize flutter, J. A. Maurer, Inc.* has been manufacturing a projection sound printer. With this form of printer it is possible to adjust the optics readily in order to focus on either surface of the image film. Prints of either emulsion position can be produced. The machine as manufactured for a decade has been able to provide sufficient illumination to expose fine-grain film (90 lines per millimeter) at a speed of 72 ft. per minute through the customary blue-violet filters with only a 32 c.p. automobile-type headlamp as a

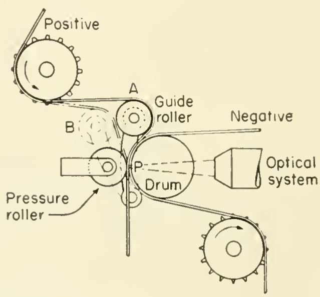


Fig. 98. Sketch of the film path of a non-slip printer.

light source. This fundamentally good mechanism has recently been redesigned and now not only provides appreciably better film motion than its predecessor, but also has improved color correction of its optical system that is essential for obtaining good resolving power in the red end of the spectrum when heterochromatic exposure is used for present-day integral tri-pack and similar color films.

Since the optical one-to-one printer provides a separate film travel path for each of the films being printed, it is possible to adjust each path for the average shrinkage of the films run in that path. Thus, the path of the machine that runs the image-bearing film can be set for the somewhat greater average shrinkage of such films than the side of the machine that runs the raw stock. The translation points of both the image-bearing film and of the raw stock are ordinarily in fixed relationship to one another because there is a common shaft or equivalent arrangement sup-

* Maurer, J. A., "Optical Sound-Track Printing," *JSMPE, 50*, 458 (May 1948).

porting the two drums or sprockets where translation takes place, and slight motion irregularities of the printing machine drive (*e.g.*, those introduced by the meshing of gear teeth), although transmitted to the shaft, do not noticeably affect the print because of the fixed movement relationship. A modern printer of this kind that is maintained in good order is capable of producing 16-mm prints with a very low flutter content. As in the case of any other optical printer, the performance with regard to resolution depends upon the optical system and, in particular, upon the objective lenses used. Figure 99 is a photo of a Maurer optical one-to-one 16-mm sound printer.

Optical-Reduction Sound Printer (35-Mm to 16-Mm). The optical-reduction sound printer is used in making 16-mm copies from 35-mm sound tracks. Since this printer is a projection printer, it has all the theoretical advantages and disadvantages that are characteristic of the general class. Many of the RCA optical-reduction printers in commercial use are quite old and have not been modified to take advantage of such newer techniques as lens coating, etc. In many, the objective lenses used are quite poor according to modern standards; those that run at a 16-mm film speed of about 36 ft. per minute usually introduce appreciable flutter into the printed film. There is great need for bringing these printers up to date in performance; an increase in film speed to 72 ft. per minute is capable of reducing the flutter, and an improvement in the lens system can increase the printer resolution materially.

New optical reduction printers that may be marketed will in all likelihood incorporate the known, but little used, improvements. This should be especially true of manufacturers that have been marketing such equipment for a number of years. Optical-reduction sound printing is important to 16-mm prints derived from 16-mm color originals in that the sound for release prints is often optically reduced from a 35-mm positive. Figure 100 shows a modern RCA optical reduction sound printer.

16-Mm Prints by Optical Reduction from 35-Mm Originals. Very little has been published on present-day methods of making 16-mm prints from 35-mm originals. The methods of high-production printing are quite highly specialized with regard to both methods and machines, and as a general rule, the laboratories that use such machinery make it themselves. Almost all such equipment is for black-and-white films.

With good processing, the losses in 35-mm printing are relatively low. It is not unusual, for example, that prints from a dupe negative can be

cut into a print from an original negative without an observable change in picture quality. It has been many years since a release print for a Hollywood picture was made from an original negative; release prints are now made almost entirely from dupe negatives. Since the film emulsions commercially available have exactly the same characteristics regardless of whether the base material is slit to a width of 35-mm or to 16-mm,

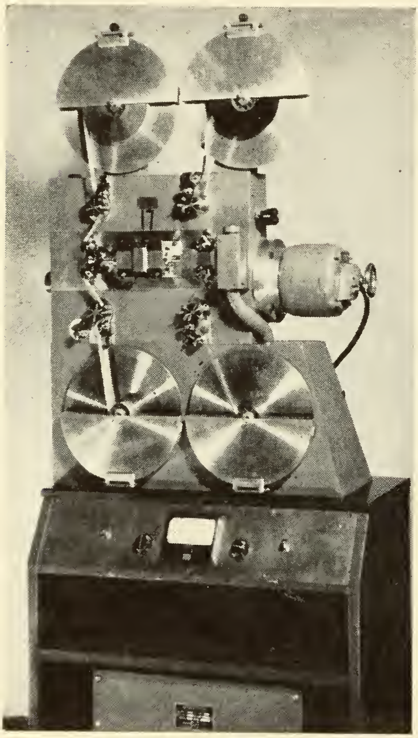


Fig. 99. Maurer optical one-to-one sound printer.

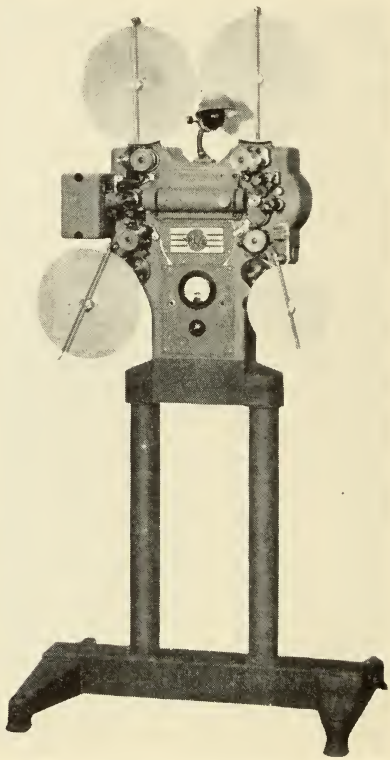


Fig. 100. Modern RCA optical reduction sound printer, PB-177. (35-mm to 16-mm).

there is a smaller loss in picture detail in a single copying step with 35-mm film than with 16-mm film if all other conditions are the same because the detail-rendering ability of the 35-mm film frame is greater in the ratio of the area of the 35-mm film frame to the 16-mm film frame.

A master positive (on Eastman #1365 developed in a negative bath) is made from the original 35-mm negative. From this master positive

is made a dupe negative, which is usually 16-mm in size (Eastman #5203 is a suitable material). Contact prints are made on fine-grain 16-mm (DuPont 605A is a suitable material). The contrast of the 16-mm print can be controlled by controlling the development of the dupe negative.

There are several noteworthy arrangements to speed up output and lower the labor cost per print; one of these is the use of 32-mm film. From the 35-mm master positive, two 16-mm combination dupe negatives are printed side by side on 32-mm film. From this point on the 32-mm film can be handled as a single strip; prints being made by contact printing and developing in the customary manner. After the 32-mm prints leave the developing machine, they are slit to provide two 16-mm prints.

Another arrangement that is used is the multiple head printer. In this machine, multiple prints—seven prints in the case of one machine—are turned out by a single machine from a single image-bearing film. The machine has a number of printer apertures in which the raw stock is fed to each and taken up from it after exposure. The image-bearing film runs through the printing machine from the feed reel, through each of the printing apertures in turn, and to the takeup reel. The number of man-hours of printing labor per print is materially reduced by this arrangement: 7 prints are exposed with a labor cost per print that is probably less than one-fourth the labor cost of exposing one print at a time. This arrangement has also been used with 32-mm film, doubling the number of prints made.

There are many other possible arrangements, and the usual objective in each case is to cut costs without appreciable sacrifice in product quality. In the making of black-and-white prints, for example, another procedure is to make a combination dupe negative for the release printing of a combination print with both sound and picture images. This is practicable for variable-density sound if the sensitometric control is well planned; it is not practicable for variable-area sound in most cases. The combination master positive or the combination dupe negative is often used in laboratories to cut costs. Oftentimes, either picture quality or sound quality (or both) suffer, since the use of the combination is often injudicious.

Printer Performance Characteristics

From the user's point of view, the quality obtained on the release print and cost are the really important items. If preservation is important, and intermediate printing copies are desired, the best quality ob-

tainable and the most careful handling is desirable. Unfortunately, there is no simple, single, quantitative measure of picture quality or of picture quality degradation, and the same is true of sound quality and sound quality degradation. Since printers are responsible for quality degradation and quality variation, some of their characteristics that are responsible should be mentioned.

Loss of Resolution. One of the more obvious characteristics is loss of image resolution. This loss may arise from many causes. In a contact printer, for example, it may be due to the fact that the image-bearing film and the raw stock are not in good physical contact, or that they shift with respect to each other during exposure. The usual continuous contact printer is designed for a specific shrinkage condition of the image-bearing film and of the raw stock. With ideal conditions, the length of the outer surface of the image-bearing film (the emulsion surface) just matches the length of the inner surface of the raw stock (the emulsion surface). For film dimensions other than ideal, the raw stock is either too long or too short to fit the sprocket exactly, and the image-bearing film is likewise too short or too long. In either event the result is a slipping of the raw stock with respect to the image-bearing film during exposure. This slipping is evident as a "smearing" of the fine detail of the image. The magnitude of the smearing depends upon the differences between the films being printed and the films for which the machine was designed.

The effect can be measured for the picture area by printing a good test film bearing resolving power test charts. The results are evaluated by checking visually to determine the just-visible lines with a microscope having a magnification of 40 diameters. A resolution test film that has been recommended is described in "Specification for 16-Mm Motion Picture Release Prints," ASA Z52.3-1944*; this was issued as a War Standard by the American Standards Association. In the test leader recommended, the effect in sound printing is measured by observing visually the frequency at which the "smear" begins on a constant-amplitude variable-frequency test.

Loss of resolution occurs in all forms of printers. It may be checked in other printers by substantially the same method. In the testing of projection picture printers, it will be found that lens aberrations, particularly geometric distortion, will be quite common. The resolving power of a lens cannot be taken for granted; when it is measured, illusions as to lens performance are likely to be shattered.

* The film described in this War Standard was not completed.

A reference test leader should be printed with every print made, and picture test leader should be attached to the edited picture original film, and a sound leader attached to the edited sound original film. These leaders should be printed through every transfer step up to and including the release prints. A check of such leaders makes it possible to measure the quality losses and deviations at every step in the intermediate process. With these data the magnitude of the losses and their origins can be determined, and steps to correct gross deviations can be planned and taken.

Contrast Increase. Printers alter the contrast of an original, increasing it in different amounts depending upon the type of printer used. A contact printer with a diffuse light source causes a material increase in contrast even though the increase is a minimum. Contact printers that have a light source somewhat distant from the aperture and use a condensing lens system to project the light to the aperture, although still fairly low in contrast, show an increase over the contact printer with the diffuse light source. Projection printers increase the contrast considerably, the greatest increase occurring with systems where the light is most nearly specular. This is the case where the light incident upon the film to be copied is approximately parallel, much as in an optical system having condenser lenses that image a small, distant light source in the projection lens. An intermediate case—which is most common, since contrast increase is usually undesirable—uses condenser lenses and elliptical reflectors combined with moderate diffusion such as that provided by a sheet of ground glass. Where maximum diffusion is desired to reduce contrast increase to a minimum, the image-bearing film may actually be placed in close proximity to a sheet of ground glass.

Commercial machines generally avoid the use of the specular optical system arrangements for picture printing because such systems accentuate very markedly scratches and abrasion marks that are located on the base side of the film. These defects are far less noticeable with diffuse illuminating systems. The commercial preference for the contact printer for picture printing can be easily understood because it has very few parts, it operates at high speed, it does not get out of order easily, it is inexpensive and its diffuse illumination system discriminates markedly against scratches and abrasions that are located on the base side of the image-bearing film.

"Smearing" due to printer slip can be avoided in contact printing of picture by using the step-contact picture printer. The step-contact

printer is widely used, and, when well maintained, is capable of providing good copies with a relatively simple machine.

The simplest way to check prints for contrast is to project them on a reference projector. It is usually possible for a laboratory to make release prints in black and white to any practical value of contrast desired. Contrast should be checked before release printing is authorized; a satisfactory trial composite print should first be produced. If a sensitometer strip is attached to the picture original and printed through all stages of release printing, it is a relatively simple matter to check contrast routinely by checking the printed strips. The correlation between visual contrast and the print-through gamma is sufficiently close for practical purposes despite the absence of an absolute correlation.

In some commercial projection printers, stray light is often so high in level that the contrast increase resulting from specular illumination is to some degree offset by the diffusion caused by the stray light. This stray light (often called flare light) has the same generic origin as in a camera objective lens; it is mostly a result of internal reflections caused by poor optical design and/or by the absence of the well-known but insufficiently used designers' trick of controlling flare light with masks or diaphragms, and by using reflection-reducing coatings on lenses and stray-light-absorbing coatings on surfaces where undesired reflections occur. In many commercial machines the theoretical optical design is acceptable, but optical performance is inferior due to the absence of these simple remedies for flare light. Generally speaking, the presence of flare light in a printer optical system is indicative of serious loss of image detail.

In black-and-white processing it is customary to reduce the development gamma (usually in the dupe negative) to offset the increase in contrast that occurs with projection printing.

Contrast Increase in Color Printing. The development contrast of integral tri-pack color film is not varied to alter picture contrast. This would not be practicable without considerable complication in the process since a change in development contrast gives rise to color-balance changes due to the variation in development contrast from one color component with respect to another, and for related reasons. Most AnscoColor and all Kodachrome is developed by film laboratories owned or under contract to the film manufacturer; at present it is believed by film manufacturers that more consistent color films can be manufactured by "tying down" the color development even at the known sacrifices than would be

the case if the added variable of variable film development were permitted.

Kodachrome—now accounting for the bulk of the 16-mm color duplicate film—is presumably processed on the assumption that there will be but a single generation of film copies made from an original, and that the copy will be made upon a continuous contact printer such as the Depue printers used in the various Kodak processing plants. Under most circumstances, a copy will suffer from excessive contrast in the amount of the increase in printer contrast factor over that of the arbitrary reference Depue printer; projection-printed copies will be particularly contrasty. Just what the design objectives of the tri-pack duplicating process may be has not been explicitly stated, giving rise to much wasteful and avoidable test-film printing. At present, the most practicable procedure for a laboratory is to make test prints upon machines whose characteristics are to be determined, and to compare them with test prints made on a Depue printer.

Because of the many compromises involved in getting the present color processes to work well commercially, it is doubtful that contrast control in color developing is likely to be considered practicable with integral tri-pack films in the near future. Physical methods such as masking seem to show more promise than chemical and developing methods; these methods may include masks that are optically superimposed as well as masking tape that is physically attached to the image-bearing film. Increased diffusion in the illumination system is also likely. For the present, exposure control and color temperature control is still rather poor in most color printing, and it is likely that there will be little effort expended in the nuances of contrast control until exposure control has been improved materially. Control improvement is under way, however, and seems to be promising. When its results show up in improved films, attempts to control contrast can be expected. The return to normal business competition will accelerate the improvement. Further data on the subject of color-film duplication will be found in a later chapter.

Printer Exposure. Since raw stock of the finest grain and of the highest resolving power practicable should be used in every step of the film-making and copying processes, the exposure required for such films in printing is of higher order than the ordinary coarse-grained films for which most printers are customarily designed. Oftentimes the increase in exposure that is readily obtained by simple modification of the illumination system of a printer is alone insufficient to compensate for the lower

photographic speed, and an increase in developer energy obtained by increasing the concentration of developer agents is necessary to obtain suitable printing densities. In the case of positive developer such as the Eastman D-16, a reduction in the amount of water by one-third has been used successfully commercially.

In order to obtain an increase in exposure of a conventional continuous-contact printer,* a mirror may be placed back of the lamp to re-direct the light rays from the rear back to the printing aperture. It will be necessary that the mirror be concave and that it be of approximately the correct focal length and located correctly with respect to the lamp and the printing aperture. A further increase in exposure may be obtained if a larger lamp is used, but if the illumination system of the printer images the filament on or near the aperture, an increase in lamp size may produce little or no increase in exposure since no additional light source areas may be effective in the system if the same condenser lens is used. Lamps of different wattage but of the same general design otherwise, differ from one another primarily in the area of the lamp filament. If an increase in illumination were to be provided by an optical system from a light source of a specified area, the intrinsic brightness of the source would have to be increased. Such an increase would be evident as an increase in the color temperature at which the lamp functions. The color temperature differences for lamps of similar design but of different wattage are relatively small. Where material increases in exposure are desired for the release printing of black-and-white films, high-pressure mercury vapor arcs with appropriate controls have been used. Such lamps provide a material increase in intrinsic source brightness and have, as well, that other desirable theoretical attribute, a relatively small source size. In all changes—regardless of the nature—it is essential to utilize every designer's trick to keep stray light to a minimum. This means reflection-reducing coatings for lenses, protective coatings for mirrors, and light-absorbing coatings and diaphragms for those portions of the optical systems where only stray light will be found. When such changes are planned, it is of course also essential that the uniformity of illumination at the printing aperture be very good if full advantage is to be taken of the improvements.

Printer exposure can be measured conveniently with a photovoltaic cell and microammeter. It will be necessary to arrange some form of mounting to fit the aperture accurately without shift in location when it

* Kunz, Goldberg, and Ives, "Improvement in Illumination Efficiency of Motion Picture Printers," *JSMPE, 42,* 294 (May 1944).

is attached and detached, and to transmit accurately the light to the cell. Lucite is quite useful for this purpose.

Light Changes. A printer light change is a change in printer illumination required to correct for the undesired density variations of the image-bearing film being copied. In conventional printers the illumination change is effected by either (*1*) a change in lamp brightness—usually effected by a variable resistance in the lamp circuit, or (*2*) a change in area effected by a change in aperture or diaphragm size, the illumination change being proportional to the change in area.

There is no standardization of either light-change methods or apparatus at all, since each manufacturer of equipment has selected some purely arbitrary way of accomplishing what he considered necessary, without giving much thought to its relation to other methods. One factor is known as printer "scale"; this is the relationship of printer-aperture illumination for adjacent steps of the light change. Most commercial printers provide 20 lights on the printing scale; a "low light" provides low illumination, and a "high light" high illumination. The "middle light, #11" is customarily adjusted to a "normal" scene with "normal" exposure and results in a "normal" print. The ends of the printing scale are adjusted to provide maximum highlight brightness and maximum shadow density, respectively; in conventional printing it is rare that the ends of the scale, #1 and #2, and #19 and #20, are used. Different emulsion lots of film have different photographic speeds and slightly different contrasts, and a compensation adjustment for "middle light" illumination must therefore be made. If the light change of the machine is a rheostat, the compensation adjustment is an auxiliary rheostat, usually calibrated in printer steps, or it may be an auxiliary diaphragm similarly calibrated. It has been customary recently for film manufacturers to indicate the relative speed of release-print emulsion with a marking on the film can indicating the speed of the film with respect to an arbitrary reference; the marking is so many points slow or fast, and refers to the Bell and Howell scale. In practice, such print stock speed markings are only guides; a commercial laboratory customarily makes test exposures, as such relative film speed ratings are determined at the manufacturer's plant and do not take into account the changes in speed that occur due to aging and storage.

To effect a change* in a printer light, it was customary in the past

* More recently, photoelectric and magnetic arrangements have been finding widespread favor. Details will be found in *JSMPE* since the last index was issued (1945).

to notch one edge of the image-bearing film at a fixed distance relative to the place where the light change is to occur. In the printer, a small roller rides the edge of the film, and when it reaches a notch, it permits a snap-action, sensitive-pressure switch to close, effecting the light change. It is unfortunate for the owner of a film that there are standards neither for the dimensions of a film notch nor for its location relative to the printing aperture. A practical result of this lack of standards is that it is impossible for a film notched for one kind of printer (*e.g.*, the Bell and Howell) to be printed upon another kind of printer (*e.g.*, DeBrie). In some cases it may even be impossible to print a notched film at all on certain printers because of some construction difference in the arrangements for guiding the film with respect to the aperture. Once a film is notched for printing, it is often no longer practicable for another laboratory to print it. For this reason it is imperative that an original picture film shall not be notched for a timed print before the original has been completely edited and is completely ready for release printing. It is also a very good reason why the choice of a commercial laboratory is a weighty one for a film owner, and should be made only after the field has been carefully checked.

World War II saw a growth in electronics equipment from one-half billion dollars a year to about 40 billions per year, and it is only natural that electronic control should begin to be considered in preference to mechanical control for the various functions of printing, and, for that matter, other laboratory functions. Current design thought leans in the direction of such control for actuating light changes. One method is to use a small "bead type" lamp that produces a directed beam of light from its filament as a light source to actuate a photocell by light reflected from white high-reflectance pieces of adhesive tape (such as Scotch tape). This arrangement would substitute for the film notch and its associated delicate switch in causing the light change to function. The use of the reflected light method of actuating light changes would entirely avoid film mutilation that results from notching. Another arrangement uses magnetized filings attached by a cement.

Printing machines are of two general designs, the enclosed light-tight type that utilizes daylight-loading film magazines to avoid fogging of the raw stock and that has an enclosed light-tight film path, and the open type that is intended for use in a photographic darkroom. The advantages and disadvantages of the two types hardly need mention, since the considerations are quite like those related to daylight-loading versus dark-

room-loading cameras. Since the loading operation must be accomplished very often, convenience is an important factor in this choice, and most commercial machines are therefore of the open type.

When a machine is loaded and operated in a darkroom, much of what the machine operator does must depend upon his sense of touch because of the low light level in a darkroom. The safelight used for general illumination may be yellow because positive black-and-white film is color-blind to yellow and red. Duplicate negative black-and-white film is panchromatic; accordingly, there can be no illumination. When Kodachrome is printed, a deep green safelight is used. In the latter case, it will be 5 or 10 minutes before a person who has not been accustomed to such illumination can begin to see after he enters such a darkroom. With light levels that are so low, it is rather impracticable to expect printing machine operators to read fine writing, make light change adjustments, and perform a number of other functions that require highly definitive vision.

When a film is printed, it usually must be "timed." The photographing exposure given every scene cannot be expected to be correct for printing, and even though the scenes appeared to be correctly exposed when the rushes were reviewed, changes in printing density are often required due to the relative location of scenes within the edited film. Thus, if two successive scenes were to show, for example, a large expanse of clear sky, and then a large expanse of dark woodland, it would be necessary to reduce the printing exposure somewhat on one and to increase it on the other to make the naturally great brightness changes less of a visual shock to the viewing audience. Changes in printing density are also required to correct for errors of exposure, and for certain effects *e.g.,* night effects) that may be desired in specific scenes. In practice, the timer in a laboratory decides just what printing light shall be used for each scene in the film to be printed. However, timing is often accomplished "by eye." Such timing is merely a timer's guess as to the correct scene density made when he views the scene in question under arbitrary yet constant viewing and illumination conditions. A Cinex machine (Fig. 101) is often used for making test prints at different densities of important scenes when a large print run is to be made. The Cinex machine makes a graduated series of test exposures that are designed to correspond to the printer lights used in the particular laboratory.

The printing operation, in essence, is the exposure of the raw stock in the darkroom as specified by the timer. There are three general ar-

rangements used commercially to accomplish picture printing: (*1*) the timing board such as the Depue light board; (*2*) the adjustable stop of Bell and Howell; and (*3*) the pre-perforated timing strip, such as is used by DeBrie. Each type has its advantages and disadvantages which become evident when it is described functionally.

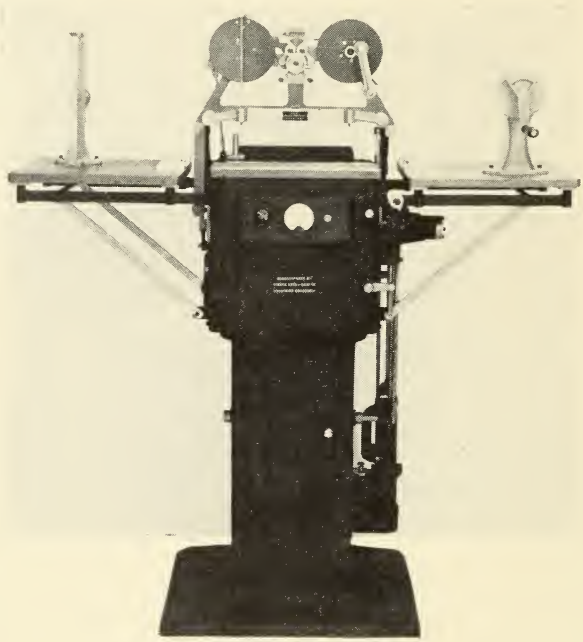


Fig. 101. Cinex light tester.

(*1*) The Depue light change board (Figs. 102 and 102A) is usually made in capacities of 76 and 152 scenes; it consists of a vertical board with 75 or 150 sliders, numbered 1 to 75 or 1 to 151, inclusive. There are 20 settings on each slider, one for each printing light. The operator sets each of the sliders in turn in accordance with the timing data written on a timing sheet provided by the timer; setting is done just before the switch is turned on to run the machine. Each slider of the light change board sets the resistance in the printing lamp circuit, thereby producing the desired exposure. The ''board,'' as it is often called, is connected electrically to the printer so that the closing of the pressure-sensitive switch that is actuated by a passing film notch energizes a relay located on the board, thereby dropping the connection bar to the printing light set up for the next scene. If several prints are to be made from a single image-bearing film one after the other, it is necessary to set up the light board only once; if single prints are to be made, it will be necessary to set up the light board each time.

(*2*) The Bell and Howell light change arrangement (Fig. 103) as used on their continuous printers is also notch-actuated. Only two scenes are set up for printing in this arrangement, the scene being printed at the moment, and the scene to follow. As each notch passes by and actuates the light change mechanism, the operator resets the aperture control lever for the scene to follow. The Bell and Howell Model J printer uses aperture control to effect a change in printing light.

(*3*) The pre-perforated light strip (Fig. 104) as used on DeBrie step printers is also usually notch-actuated, atlhough it may be operated by a separate perforated strip moving at a speed that is a definite fraction of the speed of the film being printed. The timing lights are represented by perforations in a timing strip placed in an appropriate positon in the machine before the printing operation begins. Prewar DeBrie machines were mostly of the resistance-variation type described earlier in this chapter.

Fig. 102. Depue 152 scene light change board.

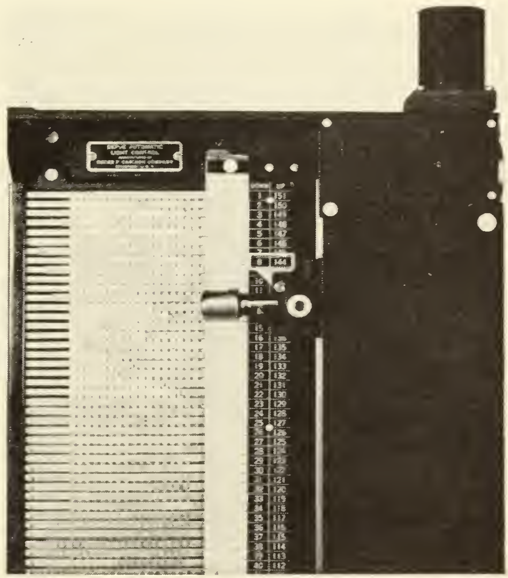


Fig. 102A. Closeup of Depue light change board.

The chance for printer light-setting error is large in the printing of Kodachrome and of dupe negatives because of the very low light levels that must be used in the printing room to prevent film fogging. This error is obviated to a large degree when the pre-perforated strip arrangement is used. If a machine is threaded properly and has made one correct print, it is impossible for a mislight to occur if the machine is set properly before the motor switch is snapped on, and if there is no malfunction. If the first scene in a sequence is properly exposed, it is an

indication that the timing strip has been threaded properly. Without machine malfunction, it is impossible for the timing of a particular scene to be different from that indicated by the punch-mark in the timing strip. Where the cost of raw film is high—as is the case with 16-mm color film—such arrangements that reduce mislights reduce the need for costly reprints.

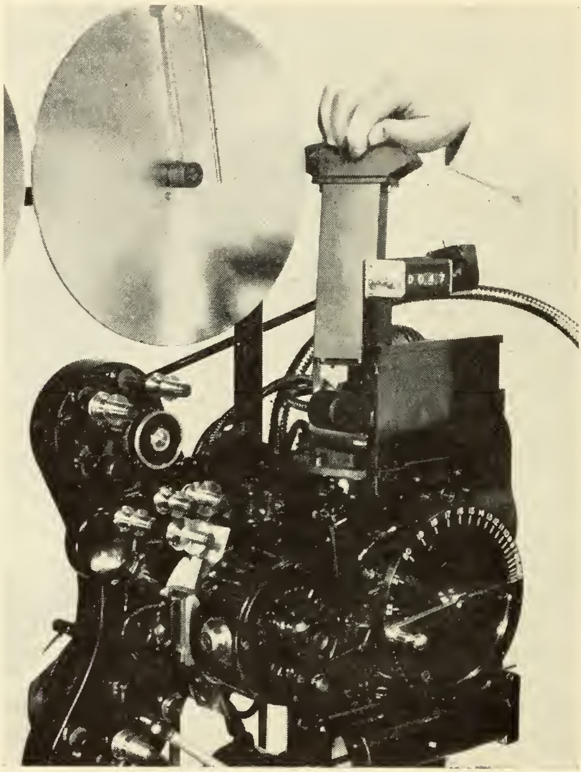


Fig. 103. Closeup of Bell and Howell light change arrangement.

There is no "ideal" light-change mechanism in commercial use. The widely used rheostat type that changes the lamp current has the disadvantage—often quite serious—that the color temperature of the lamp changes every time the current changes. The diaphragm type of light change has a more limited light-variation range than the more widely used rheostat type; although the color temperature of the lamp may be kept constant, the specular quality of the light changes with diaphragm

setting, usually becoming more diffuse with wide openings, and more specular with small openings. In certain cases such as in the printing of color film a combination of the two light control arrangements may be used. The procedure in one commercial laboratory was to set the lamp color temperature correctly for the middle light (#11), adjusting the intensity by means of an iris diaphragm. From that point on, changes in exposure were obtained by a rheostat-type light change; as in conventional printing, a low light was obtained with increased resistance in the lamp circuit and a high light with decreased resistance. "Normal" scenes were printed on the middle light where both the color temperature and the illumination level were correct. This compromise procedure worked quite well despite the change in color temperature that occurred. (Details of the magnitude of the changes will be found in a later chapter.) On the basis of experience with a wide variety of films printed in this manner, the changes in color temperature that occurred seemed much less objectionable than the "unevenness" of the uncorrected scenes.

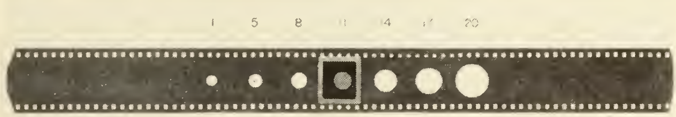


Fig. 104. DeBrie pre-perforated light strip. (See Figs. 95 and 96.)
(Filter shown covering light #11.)

The "normal" adjustment for color temperature is obtained by setting the lamp current of the printer at the reference current determined by a photometric testing laboratory for the particular lamp used. The "normal" diaphragm setting can be obtained by printing a black-and-white film of density 1.0 in such manner that a "balanced" color print will yield a density of 1.0. Once this has been achieved, the illumination at the aperture can be measured. For the same printer operating at the same color temperature the same illumination will provide the same exposure. For printers of the same type, the illumination value found for one can be used as a guide for determining the illumination value for the others, but there will be significant though small differences from one machine to another. In addition to diaphragm control for reducing the illumination at the printing aperture, it is possible to use neutral density filters. Should an increase in diffusion be desired, a ground glass may be used to reduce the light level. The exposure reducing means used—regardless of its kind—should not be used in an imaging part of the illu-

mination system, since a reduction in print-resolving power is likely to occur.

In conventional printers using incandescent lamps for light sources, it is possible to utilize simultaneously a diaphragm change and a rheostat change to obtain scene-by-scene color balance change, using, *e.g.*, 3 light sources limited to the particular color bands that the particular sources are to print. Going another step farther, it would be convenient to control contrast. This can be done by reducing the exposure time and increasing the intensity of the exposure, and by masking (or its equivalent). If all the desirable features of control were incorporated, the printing machines would be quite different in appearance at least from that which we have today. Due to the great growth in the use of electronics, evidence of such activity is already to be found, and it should not be many years before a color-printing machine will be more of a maintenance problem for an electronics technician than for a mechanic.

Printer Exposure Consistency. It is even more important to attain consistency in printing than in exposure of the original. In original photographing, there are many variables not within the realm of accurate control, and correction for most of these must be applied at the laboratory. In outdoor photographing, for example, the cameraman has no control over the brightness of the source (the sun), he can merely adjust the iris diaphragm of his camera lens, etc. In the laboratory, however, it is possible to adjust brightness characteristics as well as spectral characteristics, and to exercise some measure of control over printer light diffusion. The ability to repeat conditions accurately is most essential to the production of good prints, just as it is essential to the making of tests.

It is just as important for constant running speed to be maintained in a printer as it is in a camera. The present trend in printer design is to supply only synchronous motors—preferably three phase—for printer drive. Such drive provides theoretically constant motor torque throughout the alternation cycle of the supply current, and if the three-phase motor is resiliently mounted on the customary rubber mounts and coupled to the printer through a resilient coupling (such as a Lord coupling), the design can mean a very material reduction in machine vibration. The rather large order of machine vibration often encountered in printers is particularly objectionable in the case of sound printers, where it introduces noise because of the ''wiggling'' of the exposure lamp filament with respect to the axis of the optical system.

In the case of a picture printer, a similar "smearing" effect occurs tending to reduce the resolving power of the print produced.

It would seem to be wasted effort to use an excellently balanced three-phase motor in a resilient mount and resiliently coupled to a printer if any portion of the main printer drive that moves the film past the printer aperture or other exposure aperture is belt-driven. Flexible drives such as belt drives and rim drives provide excellent mechanical smoothing and filtering in the case of good designs for turntables for disk recording. Unfortunately, the big disadvantage of belt drive in a printer is that the slip is not constant and varies in an uncontrolled way over too great a slip range for really high-grade performance.

The importance of constant supply voltage to the printer exposure lamp can hardly be overestimated. In order to avoid stroboscopic effects, it is usually necessary to use only direct current for the picture printer exposure lamp. The use of alternating current causes variations in density from frame to frame along the film. Only direct current is, of course, suitable for the exposure lamp of the sound printer. "Ripples" in the supply of current to the exposure lamp of the sound printer will show up as additional hum and noise. If the "ripples" are due to insufficient filtering in a rectifier used to supply the lamp, or if they are due to a large commutator ripple of a generator that is insufficiently filtered, they will show up as hum in the first case and as the whine of the commutator in the second case. Since it is desirable to maintain all variable-area sound track densities within 0.1 of the nominal density, the density variation in a single 400-ft. reel should be minute, preferably one-fourth of the permissable variation. Where it is possible to use low-voltage lamps for printing, such as is the case with many sound printers, the lead storage battery is a really good source because of its excellent regulation. If a battery of large size is used (200 amp.-hr. or larger), the storage battery proves to be an inexpensive as well as reliable source of well-regulated current.

Technical Control

Technical control has as its prime function the maintenance of consistency of quality of the film processed; its secondary function is to determine what is needed in an individual case to obtain the best practicable result with the materials and methods used. To accomplish these objects it has test equipment and test procedures, and—just as important—it has the authority to order changes in production procedure to accomplish its objects.

One of the first problems is the consistency of developing. Some cans of film of a single emulsion and lot number are set aside for reference. Each day—usually several times a day—a piece of the test emulsion is exposed with a reference exposure, and developed at "standard time"; the results of the exposure are read on a densitometer. More often than not, the reference exposure is provided by an Eastman IIb Sensitometer. Eastman Kodak provides accurately calibrated lamps for the sensitometer to make it possible to hold the exposure variation within the required range. "Standard time" is merely the reference developing time for the particular developing machine under the particular set of conditions, and usually refers to the developing time at which most film is processed in a specific laboratory.

The exposures provided by the reference exposure device (such as the Eastman IIb Sensitometer) are compared with the exposure provided by a reference setting of each printer to be operated. This comparison provides a means of determining the amount and the nature of the "drift" of the exposure in a particular printer compared with the reference. An auxiliary rheostat or auxiliary diaphragm adjustment is made on each printer to return it to the operating "norm" from which it has deviated. Day-to-day checking is necessary for many reasons, not the least of which is that no two lamps are ever alike, and because the output of a particular lamp drops off with age as the lamp bulb blackens. In optical systems where the lamp filament is imaged—as in the case of an optical printer and certain contact printers where the light source is an appreciable distance away from the printer aperture or gate—the lamp filament may sag when the lamp is heated. In this event, the illumination field becomes uneven and the output of the optical system drops off markedly. Fortunately, when lamp filament sagging takes place, the filament does not ordinarily drop suddenly but tends to sag gradually.

Technical control also has as its function the production planning needed to obtain the desired result in particular cases. A particular print contrast can be obtained in an almost infinite variety of ways. An increase in developing time can be offset by a decrease in exposure, while a decrease in developing time can be offset by an increase in exposure. Printers operate ordinarily at a single speed for a particular kind of film (it is neither practicable nor desirable to change the printer speed while the printer is running), and prints are therefore often "saved" in laboratories by reducing the developing time in the event

of overexposure in printing. For relatively small changes in developing time, the reduction in contrast is not evident—particularly to the uninitiated. For reasons already given, it is usually the practice of commercial laboratories to "standardize" on a reference developing time for a developing machine and to make all other corrections (such as the correction for the speed difference between the reference emulsion lot of film and a particular lot being printed) in the auxiliary exposure adjustment of the particular printer used.

Print Inspection. The subject of print inspection is usually approached with trepidation; it is one of the "delicate" subjects encountered in the motion picture industry. The reason for this attitude is related to price; good inspection is costly while prints are usually cheap. No laboratory cares to admit that its inspection is inadequate or faulty.

If a customer wants good inspection of the films that he has ordered from a laboratory, he must be prepared to pay the price. Good inspection is very valuable, yet, what has been aptly said in connection with other products applies equally to film; "Nobody can inspect quality into a product; it has to be built into it." *All that inspection can be expected to do is to reject that which is bad; it cannot improve any product already manufactured.*

It must be frankly admitted that statistical quality control, although very widely used to very good advantage in so many industries (notably the manufacture of telephones), is almost unknown as a routine procedure in the manufacture of release prints. Statistical quality control is very widely used in the manufacture of raw film by film manufacturers. They use this most valuable mathematical tool to keep their product quality at a maximum level and their inspection costs at a minimum. The remarkable reliability of such a complex material as raw film is a tribute to the film manufacturers' use of statistical quality control to make an excellent product at a low price to the user.

To get the most out of statistical quality control requires the collection of test data. These data are collected by inspecting each and every print for a short period of time at least. As has been pointed out before, film users are at a serious disadvantage because there is no single standard measure of quality for either picture or sound, nor is there any single standard measure for quality degradation steps for either picture or sound. Thus, a very serious problem that confronts any progressive laboratory manager is to determine just which attributes should be checked and which should not. The nature and extent of the checking

of quality attributes is very closely related to the cost of the inspection just as it is in any other manufacturing process.

There has been no universal agreement upon the attributes for which tests should be made, nor has there been agreement upon the relative importance of those known to be important. The first major step in the direction of resolving this question occurred when the American Standards Association War Committee on Photography and Cinematography Z52 was set up at the joint request of all American Armed Forces during World War II. An all-too-common attitude in laboratory management is that quality standards for prints and how they are established and maintained is of no concern to a purchaser. It must be admitted that the measurement of quality and of quality degradation is a complex matter with many variables, the effects of which have not been statistically related to the over-all quality, or to the over-all quality degradation in a release print. This is a challenge to progressive managements.

An agreement upon a specification and upon methods of testing was ultimately reached during the last war; this was American War Standard Z52.3–1944 ''Specification for 16-Mm Motion Picture Release Prints'' which was approved May 29, 1944. Like all War Standards, this standard expired with the end of the War.

At this point, a few remarks may be made concerning print inspection and print quality in general; these remarks are merely an extrapolation of the widely accepted theory of quality control as it applies to *any* manufactured product.

Theoretically, when a product is manufactured, it is offered for sale to a prospective buyer. It matters little whether the buyer be an individual, a corporation, a government, etc. Once the product is manufactured, it is a *fait accompli;* the quality is what it is, and nothing but further work can change it. Thus inspection can make the product neither better nor worse.

If the purchaser has had no prior experience with the seller, it is reasonable that the purchaser shall be more concerned about accepting something that is defective than he is about rejecting something that is good. If the product is not similar to that made for others or if the product made for others is not subjected to the identical inspection desired for the product being purchased, the experience record of the seller with other customers is of no advantage whatever to the purchaser. Statisticians consider this the lowest of the three orders of control; it is very costly, since all items must be inspected for all attributes. This is called 100% inspection.

If over a period of time, the seller has been delivering items to the purchaser, and the purchaser's inspection shows that all items delivered are satisfactory in every print, it becomes apparent that such 100% inspection on the part of the purchaser will result in a waste of man-hours because of duplication that serves no useful purpose. It is reasonable to believe that in a short time it should be possible for the purchaser to reduce the amount of inspection to an intermediate stage, and later on possibly to reduce the inspection still further to a final inspection stage where only a small percentage of the product is inspected. The mathematical criteria for these three stages of inspection are found by calculation in accordance with the methods outlined in the American Standards Association references mentioned earlier.

The "quality" of the product should determine the amount of time and money to be spent on inspection by the purchaser. *Regardless of the manufacturing quality level, inspection of prints by the purchaser is still necessary.* There are few situations where projection once by the purchaser of each complete reel is not fully justified and distinctly advantageous. It is usually "penny wise and pound foolish" to think that the purchaser cannot afford it.

Print inspection by the laboratory has a double objective, one of which is to make reasonably certain that the customer will have no reason to reject the print offered for sale. The other objective is to measure the quality of the particular print and its quality deviation from the "norm," and from the design objective of the print-making process. It should be assumed that the customer's inspection is critical and will result in rejection for just cause. The laboratory inspection, however, should be even more critical in order to ascertain that a defective print is not offered for sale, and that a particular kind of defect does not recur. No commercial laboratory can make a profit if the reprint percentage due to poor control, errors, carelessness, and other related causes of defective prints is not kept to an absolute minimum.

The simplest form of inspection is projection of the print under test on a good 16-mm sound projector used under suitable conditions. A trained inspector looks at the projected picture and listens to the projected sound without interruption throughout the complete reel to be checked. The screen should be similar to that described in American War Standard Z52.56; the projector should have all the features possible specified in American War Standard Z52.1. Although these standards are no longer in force, their requirements describe products that

can be manufactured, and may be used as a guide in the choice of available equipment despite the fact that few commercial products can be expected to meet all the requirements.

The print should be inspected at the standard sound speed of 36 ft. per minute and should be viewed and heard with the same equipment and from the same observation position at all times. The equipment used should be kept in good condition at all times and should not be altered nor controls re-set unless improvement is very important. Such changes should only be made after the inspectors have had the opportunity to make a large number of "A-B" tests on the "before" and "after" conditions. Since the performance of commercial 16-mm sound projectors varies over a very wide range from one make to another and from one model of a particular maker to another, it is desirable that all machines for routine inspection be of the same make and model, of current manufacture, and tone controls set in the same manner. For such service Bell and Howell projectors seem to be as well suited as any. Such machines should always be operated with the same tone control setting on all machines at all times; the proper setting is best determined by running an SMPE multi-frequency test reel. Data concerning performance variation of different commercial machines may be obtained from Bureau of Standards Circulars C437 and C439. Although the data found in these bulletins are several years old, they show quite clearly the range of variability, which does not appear to have been materially reduced in the intervening years (see Chapter XIII).

On the average it requires 15 minutes to run one reel of film. With present wages of inspectors at over \$1.50 per hour, 40¢ per reel is needed to pay for the inspector alone. If to this cost is added the overhead (which includes the cost of inspection space, projection equipment, electric current, lamps, and general overhead), the cost of inspecting a single 400-ft. reel can easily reach \$1.00 or more. If the print is one of a very large number of mass-produced 16-mm black-and-white prints that sell for about 1.5¢ per foot, an inspection cost of \$1.00 would represent 16% of the print cost. If, however, the film to be inspected is a Kodachrome dupe print which costs about 10¢ per foot, an inspection cost of \$1.00 represents but 2.5% of the print cost. In the former case, a customer could hardly expect a laboratory to perform a complete projection inspection of every print; in all likelihood the laboratory would inspect one print in every 10 or 20. In the latter case (as for Kodachrome), however, a customer should expect a laboratory to perform a

complete projection inspection of every color print—and the smart customer will inspect it himself to make certain that the print is everything it is supposed to be.

Picture Inspection. An important characteristic of a release print is picture detail, and it is important that the inspector view the screen in such relation that he is capable of seeing it. The theoretical resolving ability of the eye is 100 lines per millimeter at a distance of 2 w (where w is the width of the screen). At any other distance, the resolving ability of the eye is inversely proportional to the distance. At 4 w, for example, the resolving ability of the eye is only 50 lines per millimeter. Inspectors should be critical of detail quality and should always view the test screen from a single distance so that mental comparisons of one print with another can quickly and readily be made with no need for "weighting" the results as would be necessary if pictures were viewed from different distances. This is best accomplished by placing a chair for the inspector in the proper place—preferably at a distance of about 2.5 w from the screen—and directly in line (as nearly as practicable) with the center of the screen. The inspector should be expected to use the fixed chair during all inspections. It should be pointed out that most projection lenses supplied commercially are definitely inferior to the resolving ability of the eye when a screen is viewed from a distance of 2.5 w. It can be readily determined if the lens used for inspection is poor; a poor lens will not provide a sharp picture in the corners when the picture is sharp in the center. Although no lens made commercially will meet a resolving power requirement of 100 lines per millimeter at the corners as well as at the center of the picture, good lenses can approach this figure at the center and show a resolving power of 50 to 60 lines per millimeter at the corners of the picture. These resolving power values represent good performance in commercial lenses, and are measured without change of focus adjustment between best adjustment for the center of the picture and best adjustment for the corners. To obtain a lens of this kind usually requires correspondence with the engineering department of the projector manufacturing company; Eastman Kodak is, in all likelihood, in the best position to supply lenses approaching such stringent requirements by selection from among the best production lenses that they manufacture. Other manufacturers such as Bausch and Lomb can also supply high-grade lenses on special order, but, because the demand for high quality lenses has been neither insistent nor widespread, prolonged negotiation with manufacturers' agents may be needed to obtain test lenses of the desired quality.

Sound Inspection. Sound inspection of release prints is—or should be—a little more involved. If we can assume that one of the purposes of inspection is to obtain information that can be used to "tighten up" the quality of processing so that improvements can be made properly, sound inspection is something more than a mere audition of the sound track. In this regard, sound is no different from picture; inspection of both should provide not only data as to the acceptability of the print, but should also serve as a positive quality index in providing suggestions for future improvements. Anticipating improvement in release print quality requires the collection of data that costs money; it is an investment in the future that deserves much more attention than it has been accorded.

For routine inspection of sound, a good quality sound projector of current manufacture such as the Bell and Howell is a good commercial reference. For the more thorough inspection of sound, the test equipment should be of such high quality and precision that a user can justifiably have unquestioning confidence in it. This can only be obtained if the equipment is of higher quality than the films that it inspects, so that performance deviations noted can be correctly attributed to the film and not to the sound testing and measuring equipment. The equipment should be good enough to show up differences in the quality of even acceptable prints made during a single run as a single batch. Such equipment does exist on the market, and no progressive film laboratory can afford to be without it even though most do not have it. This equipment is also used for inspecting fine-grain sound-track prints to be used for re-recording and for other critical sound films.

In essence, the equipment consists of a high-quality film phonograph, a wide-range amplifier, and a wide-range loudspeaker. Despite the low level of the air-borne noise that it makes while running, the film phonograph should be located in a room other than the listening space. The listening space should be acoustically good, and as free of extraneous noise as possible. Each item of equipment should be consistent in performance over long periods of time, and with ordinary maintenance and inspection the recommended items are capable of furnishing such performance.

The film phonograph may be a Maurer unit of current manufacture, factory-equalized for "output flat to 10,000 cps." This machine has very good film motion and has a good chromatically-corrected optical system providing a slit of approximately 0.3-mil width. The optics

of the machine* may be adjusted at will to scan either the near surface or the far surface of the film; the adjustment shift of 0.006 in. (which accounts for the film thickness) is obtained by two preadjusted limiting stops. An exciter lamp of 2-amp. rating is used; since the cross-section of this lamp is quite large compared with the 3/4- or 1-amp. lamps widely used in sound projectors, the microphonic noise generated by exciter lamp vibration is materially lower than that in a sound projector. A preamplifier, feeding an output transformer, is mounted in the base of the machine. The Maurer output impedance is 200 ohms; Western Electric uses 600/150, RCA 250/500. (Standardization of performance measurement and of impedance is urgently needed.) A power supply provides all d.-c. current required by the machine; this includes exciter lamp current, heater current for the preamplifier, and high voltage for the preamplifier plate circuit and polarizing voltage for the photocell. The film phonograph uses a single-phase synchronous motor for film propulsion. The mechanical vibration that occurs is quite low yet it is greater than would be the case if an equally well-balanced three-phase motor might be used. A selected nonmicrophonic tube type such as the 1603 would be a better choice for the first stage than the commercial electron tubes that are used. The performance of the machine as supplied is quite good with regard to microphonics despite this lack, chiefly because of the good gears which generate a relatively low level of vibration, and because of the tube suspension mounting that is used to attenuate the disturbances reaching the tube.

A suitable amplifier combination which has sufficient gain and output power is the Western Electric 142B. It also has a reasonably low noise level and a wide frequency range extending to 20 kc. The input should be connected for 200 ohms to match the impedance of the film phonograph, while the output should be connected for 4 ohms to feed a W. E. Company 757A loudspeaker. Instructions for making impedance-adjusting connections in the amplifiers are found in the instruction book supplied by the manufacturer. A "tee" attenuation pad may be used between the film phonograph output and the 141 amplifier input for volume control.

As it is convenient and useful to be able to check the response-fre-

* The newer Maurer film phonographs do not provide for focus shift. In these machines it is necessary to turn the film over and run it in the opposite direction in order to have the sound track in focus.

quency characteristics of the film phonograph and its associated amplifier, an output control box should be connected between the output* of the 142B amplifier and the loudspeaker. This box may contain a standard VU meter (Weston) with its associated Daven TA-1000-2 attenuator, a double-pole double-throw toggle switch, a 600-ohms resistor to be used as a dummy load, and the necessary interconnections. When the toggle switch is in one direction, the volume indicator is connected across the dummy load for measurement purposes; when the toggle switch is in the other direction, the volume indicator is connected across the loudspeaker. Meter readings are more steady and consistent when taken across a dummy load rather than across a loudspeaker; all readings that are entered in a log should be made in this manner. Figure 105 is a schematic diagram of the connections using a Jensen HNP-51 loudspeaker which is of correct impedance for direct connection.

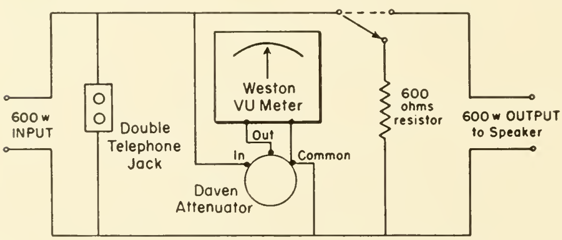


Fig. 105. Audio output control box.

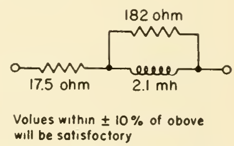


Fig. 105A. Jensen loudspeaker HNP-51 woofer-simulating network.

As ordinarily used, the loudspeaker should have its high-frequency response control switch in the "wide open" position. The hiss and distortion produced will be clearly audible, and variations from one print to another should be evident to some extent. To make the differences more pronounced, a woofer-simulating load (Fig. 105A) may substitute for the low-frequency cone by connecting it through a double-pole, double-throw, toggle switch. This removes the low frequencies (below the crossover frequency of the speaker), leaving only the high frequencies being reproduced. Such removal of the low frequencies in reproduction removes the sounds that mask the noise and distortion, thereby making it more evident. Routine listening would be done with the full range of the loudspeaker; only critical cases would require low-frequency removal by switching. Such testing and listening can be considered analogous in a sense to the use of low magnification for rou-

* A Western Electric 18A autotransformer is needed to adjust the output impedance to the 600 ohms input value of the control box.

tine examination with a microscope, and higher magnification for detailed examination.

It must be recognized that the above equipment is not "front parlor" equipment as it attempts to *show up* noise and distortion rather than to conceal it as is customary when high frequency response is cut off by low-pass filters or by amplifiers and loudspeakers* of limited frequency range. If it is desired to operate this equipment under "front parlor" conditions, it will be necessary to use an appropriate low-pass filter to limit the high frequency response to the useful range, the range where the noise level is not excessive. The performance of high grade 16-mm sound tracks on such equipment proves quite an agreeable surprise when heard for the first time.

It is possible with the Bell and Howell sound projector to install a special photocell input preamplifier that is similar to that in the film

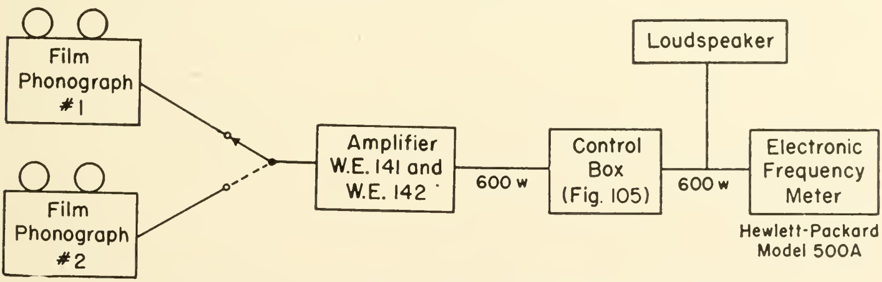


Fig. 106. Print comparison sound measurement schematic.

phonograph. This will make it possible to listen to a combination print with the same high-quality amplifier and loudspeaker system as used with the film phonograph. Although the over-all quality will not be as good as that from the film phonograph due to higher flutter, poorer high-frequency response, and a poorer signal-to-noise ratio, the degradation suffered is not excessive and, accordingly, the arrangement is quite useful in checking more accurately the sound quality of prints. Oftentimes it is advantageous to be able to make "A-B" comparison tests. To accomplish this, provision can be made for switching between two film phonographs or between two Bell and Howell projectors arranged with photocell input preamplifiers (Fig. 106). If the projectors are used, it will probably be desirable to have synchronous motor drives, so that comparison testing can be accomplished in synchronism since commercial sound projectors are ordinarily equipped with governor-controlled or induction motors which do not run at synchronous speed.

* See pages 300–303.

Practical Laboratory Operation

A commercial film laboratory is primarily a business, and like any other business it is operated for the purpose of making a profit. The product of the business —prints—must be competitive in quality and in price with similar products made by others. If a higher-than-average quality is desired, it should and does command a higher price. The increase in price above average is related to the increase in utility of the better product to the user; this may or may not conform to the increase in cost necessary to produce it. In most cases a large increase in quality does not command a large increase in price because the market usually cannot justify such an increase. Despite this, there are special cases where a large increase in quality will command a substantial increase in price; there are even a very few cases where the best quality obtainable commercially is so badly needed that the high cost is justified almost regardless of where it may fall (assuming efficient plant operation).

The practical process of buying prints is complicated by the fact that there are no hard-and-fast standards by which the quality of the prints can be measured accurately. The customary procedure that is followed in making prints in large quantities is that a trial composite print is prepared by the laboratory, examined critically by the buyer, and corrections suggested. If the suggestions are feasible, the laboratory prepares a second trial composite print for the buyer's inspection. Ordinarily no further corrections are required beyond this stage, but if they are, the buyer deals directly with the laboratory's responsible representative and decides just what to do. As soon as a fully acceptable trial composite print is made, the buyer authorizes the laboratory to proceed with his order. The laboratory often retains the final trial composite print as a reference sample so that questions regarding specifications may be settled easily by direct A-B comparison with the reference.

Although this practice for quantity production of prints is almost universal in the film industry in the United States, practical variations of it occur where small quantities of prints are made. On the whole, these variations make an attempt to recognize the realities of the situation in that it would be impractical, for example, for a laboratory to make 3 trial composite prints if only a single release print were to be ordered. In practice, only one print would be made in a case of this kind, with a second one being made only if the first were quite wide of

the desired mark. Laboratory business policies are as widely different as people are different. The general rule that is applicable governs all business transactions; if the manufacturer's product is defective in material or workmanship, he repairs or replaces the defective component. In a film, this may mean the replacement of a "section" (a portion of the film or it may mean the making of a completely new print. Ordinarily print replacement policies are most liberal where the print quality is highest. There are no fixed rules, either for the 16-mm laboratory industry as a whole, or for particular laboratories in it. Much depends upon the buyer's knowing the laboratory, and the laboratory knowing the buyer; in many laboratories each order represents a specific negotiation between laboratory and customer.

Since there are no hard-and-fast rules governing the handling of small print orders, it is necessary that the buyer make his wishes perfectly clear to the laboratory with regard to how his prints are to be made. In some rare cases, it is possible that the exposure of the picture original is quite "even" and needs little correction, and the improvement by timing would not be worth the increase in price; a one-light print would then be ordered. In most cases, however, timing will be required, and the buyer should tell the laboratory the special requirements to be met—if any; it is often a good idea to provide a "shot list*" with notations as to special scene density requirements, etc. If the printing requirements are at all critical, the buyer may request the laboratory to check with him when the film is to be timed. Such procedures can aid in removing uncertainty in the dealings between the buyer and the laboratory, and, in doing so, make possible a material improvement in print quality as desired by the buyer.

In a business as competitive as a film laboratory, considerable capital investment is required in the machinery necessary to do the work well. Although the turnover is far more rapid than in heavy industry, and the investment required is much smaller per dollar of sales, the business is dynamic—constantly changing and improving. A small segment of the buying market can be relied upon to be interested in the best quality product commercially feasible, and is prepared to pay the extra cost that the better quality involves. The large segment of the market is interested in the high quality product but feels that the price is currently "out of line" with the value received; eventually, however, the better quality is available to this market at little or no increase in price as the general quality level rises.

* See Figure 75.

The core of the average laboratory's business is release prints. Although the variety of other services is quite wide, almost all of these services are "feeders" of the release print business. The reason is quite simple; it is in release printing that the economy of mass production can make itself felt in terms of lower prices, better quality, and better profits (even though the unit profit is small). Limiting waste and errors is very important; this is one of the reasons why all laboratories abhor "reprints." A reprint is merely a job done over again at laboratory expense because the laboratory inspector finds the quality of the film he has tested unsatisfactory for shipment to the customer. In a well-run laboratory, reprints account for but a small percentage of the total laboratory output. Release print raw film is an appreciable part of the price of a print; it costs the laboratory about 0.6¢ or more per foot for black-and-white positive film, and about 5¢ per foot for color duplicating film. With such high material costs and with continually rising labor costs, no laboratory can afford many reprints.

Production operations are performed in a routine manner. If specific instructions are not provided, the laboratory will use its best judgment in accomplishing the work to be done. Laboratory personnel are called upon to make a large number of "snap decisions" every day, mostly associated with the immediate aspects of making prints. A buyer of laboratory services should acquaint himself with the processes of the laboratory so that he knows and understands what the processes are, even though he may not understand their technology. The laboratory representative, in turn, should be acquainted with the production and other facilities at the command of the buyer, as well as with his purposes. With this knowledge, much closer cooperation and better prints should be possible to the mutual benefit of both parties.

Printing 16-Mm Picture from 16-Mm Originals. In making 16-mm black-and-white release prints from 16-mm original picture film such as black-and-white reversal or color tri-packs such as Kodachrome and AnscoColor, the most practicable procedure is to make one intermediate film, a black-and-white duplicate negative, from which release prints are made. For best quality uniformity of release prints with lowest price, the edited original film is timed to provide the duplicate negative; the timing shall be accomplished in such manner that the release prints can be made at a single printer light setting. With this procedure, the print-to-print uniformity of the release prints should be very high, the speed of printing may be high, and the cost of the release prints relatively low.

A good duplicate negative requires raw stock of the highest resolving power practicable. It should be the very best intermediate film copy that we know how to make—almost regardless of cost. Since it may be used to make several hundred prints, it would seem practical to spend almost as much money to correct a deviation in the dupe from that which is considered ideal as can be spent to correct that same deviation in each and every print to be made. In a sense the relationship of a dupe to a film laboratory is similar to that of special production dies, jigs, and tools to a mechanical factory. The automobile industry long ago pointed out the business wisdom of buying costly but accurate tools for the mass production of products of high mechanical quality. Where the mass production of high quality prints is the objective, it would seem to be similar business wisdom to determine what *is* the best dupe that can be made almost regardless of cost—and to go ahead and make it. Should an error or deviation be found in a dupe that has just been made, it is wise to scrap the defective dupe and to make another that eliminates the defect.

The raw film most suitable at present is Eastman 5203 duplicating negative. A good procedure is to print this film on a step-contact printer. Although such a printer is slow when compared with commercial continuous printers, the quality improvement should be observable in the release prints. As used commercially in one laboratory, the film is developed in a glycin developer at a relatively low gamma, yielding quite high-speed developing (compared with negative developing times). The cost of the dupe negative is correspondingly low and the resolving power and graininess quite low compared with the more customary 6-min. developing time in Kodak SD-21 developer at a development gamma of about 0.65. Because the effective speed of the film is materially reduced by the reduction in development gamma, appreciably more light is required in the printer for proper dupe negative exposure and the running speed of the film is comparatively slow in the printer.

Only fine-grain release print raw film should be used. The dupe negative has been made for one-light printing, and no light changes are required during the release printing operation. If high printing speed is required to obtain low printing cost, a continuous contact printer may be used. If somewhat better picture quality is required, a step-contact printer may be used, resulting in lower speed and somewhat higher print cost. At present, DuPont 605A would seem to be the preferred raw stock due to a difference in the shape of the toe of the H and D curve; East-

man 5302 appears to have slightly better grain characteristics. Both films have a rated resolving power of about 90 lines per millimeter.

Only one grade of release-print, color-reversal, raw stock is generally available; the resolving power of both the Kodachrome and the Ansco-Color is about the same despite the marked differences in color reproduction. There is no special intermediate duplicating film available, since both manufacturers have felt that it would be a mistake to encourage anything beyond two generations of prints with the relatively simple methods and inaccurate control now common in most integral tri-pack color film printing. Intermediate duplicate color reversal copies have been successfully made in the past, but a much higher order of control was necessary to make such operation possible. In the absence of special intermediate materials, comparative tests should be made upon all practical materials available, including raw film for original photographing as well as for duplicating. If an intermediate color reversal duplicate is made, it should be possible to effect all off-balance color corrections and all timing corrections in the intermediate duplicate; once more it should be possible to make all release prints at one printer light setting with neither color change nor intensity change in printing. Much trial-and-error work will be required since film manufacturers do not provide transmission-characteristic data for any of their color filters or of the filter dyes that they use in the films they sell. Since it is generally understood that the filter dyes used in films for original photographing are of the broad overlap type, and the filter dyes used in the duplicating-type films are of the narrow overlap type, combinations of original-type film with sharp-cut filters should show different results from duplicating film with wide-band filters. All special color filtering should be done in the intermediate duplicate if used; the release-printing operation should be one-light printing with no color correction from one scene to another in the reel. Surprising results can be obtained with special exposure techniques, particularly if the exposure level is accurately controlled, and overexposure is studiously avoided. Overexposure is to be avoided in the original as well as in the duplicate. While better quality can usually be obtained by underexposing the original approximately 1/2 light stop and increasing printer illumination by the corresponding amount, caution must be observed when Kodachrome Commercial is the original. Further details concerning color and color duplication of integral tri-pack films will be found in Chapter XIV.

Printing 16-Mm Picture from 35-Mm Originals. To make good 16-mm release prints from 35-mm originals requires similar procedures. Among

the additional factors to be taken into consideration is that the original negative will be exposed and developed in the manner customary for the making of 35-mm contact prints. Within the past decade or so it has been rare that 35-mm release prints were made from the original negative. Ordinarily, dupes are made not only for the purpose of permitting simultaneous printing of a particular subject at different laboratories located at widely separated points, but also for the purpose of preservation, for the introduction of effects such as fades, wipes, dissolves, etc., for the preparation of foreign versions of films, and for the preparation for 16-mm release printing. If this large variety of purposes is to be served from the same original negative material, it can only be accomplished with dupes. To obtain the best release print quality for each particular purpose, the duping process in each instance takes into account the projection conditions for the release prints quite as much as it allows for the increase in contrast caused by the additional printing steps involved. In general, printing increases picture contrast; the increase is a minimum when diffuse printer illumination is used, and a maximum when specular illumination is used. "Printer factor" is a common trade term used to express the ratio of the contrast of a copy to the contrast of the film being copied, under the theoretical condition that the development gamma is unity. (Printer factors are always greater than unity.) To offset the contrast increase due to the printer, development contrast is reduced. The increase in contrast of a good projection printer such as a 35-mm to 16-mm optical reduction printer is appreciable, and the development gamma of the dupe negative is ordinarily reduced to compensate for the contrast increases due to printing, since it is also possible to reduce print graininess materially in this manner. Fortunately, a slight increase in contrast of 16-mm prints is required as compared with 35-mm prints, and is desirable because of the lower color temperature and the lower illumination level of the average 16-mm projector compared with the average 35-mm projector. This contrast increase is quite small, however, compared with the contrast "picked up" during the extra printing steps.

Assuming that no effects such as fades, wipes, dissolves, etc., are required in the edited original negative, the procedure for making 16-mm prints in the conventional manner (not specialized for quantity production) is a three-step procedure. The first step is to make a one-light 35-mm master positive of the picture on Eastman 1365 duplicating positive 35-mm film. This film can be printed on a step printer if best

quality is to be preserved, and developed in a negative-type bath such as Eastman SD-21. From this 35-mm master positive is made a 16-mm reduction dupe negative, on Eastman 5203 stock, which is timed to make the corrections in scene density required to permit the dupe negative to be printed at a single printer light setting. The dupe negative bath should have as low a gamma as possible—consistent with the desired release print contrast—in order to provide 16-mm release prints of minimum graininess. It should be remembered that the master positive material is "color blind," being responsive only to blue and shorter wave lengths; the dupe negative material is panchromatic and responsive to all visible wave lengths. Gamma may be reduced somewhat in the dupe negative if the illumination is limited to the blue and near ultraviolet region of the spectrum. This can be accomplished readily by use of suitable color filters. In general, in the process of duplicating and copying, it is the gamma product from the original film through all steps to the release print that determines the over-all contrast. Two different printing setups will provide substantially the same print contrast when the over-all gammas of the setups are the same. Since contrast is but one of the important characteristics of a print, two prints from the same original made by setups providing the same over-all gamma will be equivalent only in contrast; there may be very significant differences in such other important characteristics as the average scene density, the rendition of the highlights and shadows, and the resolving power of the prints.

Sound Printing. Unfortunately, the problem of sound printing is not as simple to analyze and to solve as is picture printing. As has been pointed out, one of the serious problems is the differences in sound performance even among modern 16-mm sound projectors. It is usually a surprise—and a serious disappointment—to listen to the identical film as played on different machines; many of the differences pointed out in Bureau of Standards Circular C439 published before World War II still persist.

Over a decade ago the Academy of Motion Picture Arts and Sciences, an organization composed of representatives of Hollywood producing organizations, when faced with a similar problem connected with 35-mm entertainment theaters, initiated a program of standardization of theater equipment characteristics which has since removed the gross variability of performance that now plagues 16-mm sound projection. All producers that plan on having products shown in 35-mm entertainment theaters

provide prints that project satisfactorily on equipment with the reference characteristics. This requirement has resulted in a form of standardization of 35-mm sound print quality that provides reasonable assurance of satisfactory sound in the average theater. Such films have fewest quality variables, and the problem of making 16-mm prints from 35-mm originals of this kind will be discussed first.

*16-Mm Sound Prints from 35-Mm Sound Originals.** First-quality, fine-grain, 35-mm release prints of Hollywood films are of reasonably good and consistent sound quality. Satisfactory 16-mm release prints of such films are made by selecting a good 35-mm print from a run, and re-recording it to a 16-mm negative that is used directly for the release printing of the 16-mm sound. The 16-mm re-recorded variable-area negative is made on Eastman 5372; in accordance with the recommendations

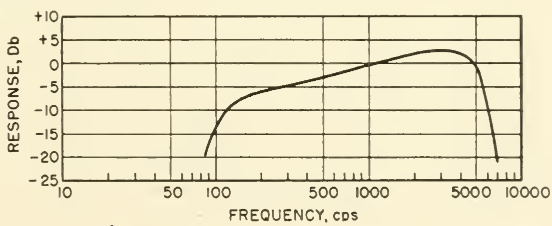


Fig. 107. Recommended response-frequency characteristic for re-recording from a selected 35-mm release print to 16-mm variable-area negative that will be contact-printed directly on release prints.

of the Committee on Re-Recording Methods for 16-Mm Release of 35-Mm Features of the Research Council, the following alterations are made (see Fig. 107):

(*1*) Compress the volume range to about 15 db—the volume range on 35-mm release prints is of the order of 35 db.

(*2*) Modify the response-frequency characteristic as follows (Fig. 107):

Cutoffs: 100 cps (low frequency); 5000 cps (high frequency)
Response: ''Tilt'' the characteristic upward approximately as follows:
Reduce response below 1000 cps—6 db down at 200 cps.
Raise response to 3500 cps—3 db up at 3000 cps.

16-mm fine-grain release print stock is presumed. The procedure recommended, while purely empirical, results in a high percentage of acceptability when a particular print is projected on different projectors. To produce 32-mm release prints in sound, the procedure has been modified somewhat to account for the peculiar operating characteristics of the 32-mm print production method. In essence, a direct 16-mm positive

* The subject is under constant study; television has been adding its urgent demands for sound quality uniformity.

is re-recorded from the selected 35-mm release print or fine-grain, non-slip sound print. This direct positive is printed on Eastman 5302 as a sound dupe negative; release prints are made on Eastman 5302.

This procedure is described in some detail in the Journal of the Society of Motion Picture Engineers of March 1946 "An Application of Direct-Positive Sound Track in 16-Mm Release Processing by Duplication Method" by G. C. Misener and G. Lewin of the Signal Corps Photograhpic Center, Long Island City, N. Y.

16-Mm Sound Prints from 16-Mm Sound Originals. The case for 16-mm sound prints from 16-mm sound originals, is, unfortunately, not as simple as 16-mm sound prints from 35-mm originals by means of re-recording. There is no standardization of 16-mm sound projection equipment characteristics; accordingly there is no single objective toward which 16-mm sound originals are directed. This variability in objective as measured by the wide variations in response-frequency characteristic found on original films is a very serious handicap when it is accompanied by the customary variability in films and film processing as measured by variations in intermodulation and cross-modulation distortion. Thus, while published data on printer loss may show a high-frequency loss at 6000 cps as small as 4 db, it is not uncommon to find losses as great as 14 db in a print. The difference of 10 db represents quite a large percentage variation if the 4-db loss is used as a reference; it is no wonder that the sound quality of prints is variable with such a large element of variability in print losses. The existence of such variability makes it imperative that the number of photographic copying steps used for 16-mm sound shall be kept to an absolute minimum in the chain between the original film and the release print.

Under the very best practical conditions, the best dynamic volume range to be expected from a 16-mm sound original is about 35 db; with pre- and postequalization, range *E* (90–6400 cps) represents the widest practical frequency range. For a very quiet listening room, a dynamic range of about 30 db may be utilized if an inspection-type reproducer such as a Maurer film phonograph is used with an associated high-quality amplifier and loudspeaker. Although this frequency range is not high fidelity (the minimum for high fidelity is 75–8000 cps), the performance will be surprisingly good as it is appreciably better than ever experienced by most users of 16-mm films. To accomplish this result not only is it necessary to use the best film equipment available, but it is also necessary to use well-filtered dirt-free processing solutions, water, and drying air. To assure cleanliness of the surface of the film, it is necessary that

it be cleaned with carbon tetrachloride after processing. Under the best conditions, there is little practical difference in available dynamic volume range or in frequency range between a film recorded as a negative or one recorded as a direct positive. When a direct positive film made in this manner is reproduced on such film phonograph equipment as that suggested, almost all of the noise heard in the loudspeaker should be the "hiss" produced by the photocell of the equipment and by the grain of the film. If it is not, either the equipment is at fault, or the film has become contaminated by dirt or other foreign matter during or after processing. To check the equipment, it is merely necessary to operate the amplifier at normal gain (amplification) with no film in the machine and with the motor of the film phonograph running. A comparison is made of the noise heard when the light beam from the exciter lamp is blocked to prevent light falling on the photocell, and the noise heard when the light obstruction is removed.

Unfortunately, the full dynamic volume and the full frequency ranges that can be recorded are beyond the capabilities of even the best commercial sound projector. The extension of either range beyond the respective capability of the sound projector as further limited by the acoustics of the listening space has the effect merely of increasing the noise and distortion heard by the audience; it is necessary to provide pre-print material that has both the dynamic and the frequency ranges intentionally limited in accordance with the reproducing limitations to be encountered when release prints are projected. This usually means a limitation of dynamic range to a maximum of 25 db and of frequency range to range *F* (110–5300 cps) for best projectors under best conditions, and to a dynamic range of only 15 db, and of frequency range to range *H* (160–3600 cps) for good projectors operated under adverse acoustic conditions or for poorer grade yet commercially acceptable projectors under average conditions. If the original recording has been made with a wider dynamic or wider frequency range, re-recording will be necessary to accomplish range-limiting.

Unfortunately, re-recording has not been handled as a regular part of 16-mm laboratory operations despite the fact that the need for it connection with range-limiting arises to a considerable degree within the laboratory and in projection. Re-recording has in the past been considered a part of production operations, especially in the re-recording of 35-mm Hollywood features for 16-mm release. No doubt one of the strong reasons for this has been the fact that comprehensive facilities for

re-recording are required in 35-mm commercial re-recording operations involved in preparing the 35-mm films, and the preparation of a re-recorded 16-mm release negative or release direct positive merely represents another job that can be accomplished readily with available, highly versatile equipment whose capital costs are accounted for within the production budgets of the 35-mm films that are produced. It must be admitted frankly that very little of this kind of re-recording has been done with 16-mm, primarily due to a lack of high-quality facilities and personnel. The trend in the future should be strong in this direction as quality demands of users become louder and more insistent.

In general, black-and-white printing is best accomplished with most suitable films when the light source in the printer is filtered to remove the longer wave lengths; in some printing near ultraviolet is used. Sound print quality for variable-area recording is judged almost entirely by listening. Although cross-modulation tests may be used, the correlation with listening tests is not ordinarily close enough for commercial operation. A common procedure in connection with variable-area recording is to make a test record of a sentence with many sibilants in it, such as: "Sister Susie's sewing shirts for soldiers," and make test prints at different exposures. The print exposure selected is the one that provides the most natural reproduced sound. The results of this test are followed by a cross-modulation test, since measurement of the latter test results depends upon meter readings rather than upon a listener's aural judgment. Once the objective has been determined, it is simpler to check variations with meters even though it is clearly recognized that the correlation may not be close. It is possible that the correlation between intermodulation testing of variable-density recording may show a closer correlation, but this has not been definitely established with 16-mm film because variable area is used far more widely.

Performance Limitations of Recorded Sound

Photographic printing of sound should always be accomplished on films of the highest possible resolving power, and processed with maximum cleanliness. In this manner the raw film itself does not seriously limit either the dynamic range or the frequency range of the finished print. The recorded dynamic range should be well within the signal-to-noise ratio of the film stock, and should never be greater than the dynamic range of the projector or reproducer on which the film is played. Should

the recorded dynamic range in the print exceed the range of the projector by even a small margin, the low level passages of the film will be inaudible, since they will be drowned out by noise. To avoid the addition of an appreciable amount of distortion and of noise—which reduces the useful dynamic and frequency ranges, all printing machinery must be maintained in best operating condition. This means making certain that the light field of the printer illumination system shall be as uniform as possible throughout the printed area, both as to intensity and chromatic quality. When the printer is running, there should be a minimum of vibration of the printer lamp with respect to the optical axis of the illumination system in order to avoid the introduction of audible noise. The propulsion system of the printer must be maintained, and sprockets and gates must remain properly aligned. Because of propulsion irregularities, measurable flutter is introduced in even the best contact printer and can be observed by reproducing a print of, *e.g.*, the 5000-cycle SMPE focus test film on a film phonograph, meanwhile observing on a cathode ray oscillograph the waveform of the wave envelope caused by flutter.

Unfortunately, most commercial film laboratories do not routinely make such tests on their equipment; printer performance maintenance measurement is still quite crude in practice. Quite often, published data found in technical journals represent the performance of an isolated piece of equipment under noncommercial operating conditions. It represents, rather, what a particular piece of equipment is capable of doing under certain limited idealized conditions rather than what its counterparts do in practice.

The noise and distortion introduced in each transfer step is quite large and varies over rather wide limits from one laboratory to another. It varies for different machines within the same laboratory and for the same machine at different times, though to a lesser degree. It is a common experience of film users to find that there is a significant difference in sound quality between the averages of two different lots of prints made at different times from the same release negative or other preprint material.

Printer loss characteristics may be checked by printing a calibrated film such as American War Standard Film Z22.44-1946. This, with its calibration, may be obtained from the Society of Motion Picture Engineers. A comparison between the standard film and the print with both run on similar film phonographs in an A-B test with a cathode ray oscillograph used for checking waveforms will quickly show up significant

differences. Level differences can be measured with a standard VU meter; the measurement arrangement was shown in Figure 106.

Fine-Grain Film and Its Application

When a new 16-mm print is removed from its shipping container for the first time, there is a momentary silence as a professional audience sees the picture on the screen and hears the sound from the loudspeaker. During this moment, the quality of the projected picture and sound is evaluated. As matters stand today, a user has no way of knowing beforehand just what quality can be expected from a print in an unopened package, since there is no quality standard by which 16-mm prints—or any other prints for that matter—are graded. It is no longer true that the output of 16-mm prints is so small and the distribution so restricted that quality standards of some sort would not be welcome.

Steps have been made in the direction of attempting to standardize the 16-mm projector. The efforts are continuing, although it has been difficult so far for manufacturers and users to "get together."

With regard to prints, there is no distinction between a print suited for an audience of three or four that is not critical and a print for a critical audience of 1000—unless we accept the term fine-grain. The distinction is vague; it is used for release prints made upon raw stock of higher resolving power (90 lines per millimeter), and usually implies vaguely the use of fine-grain films for duplicating. We have no term at all to describe prints made on poorer materials. There is no precise explanation as to what "fine-grain" means or how "fine" a film must be to merit suitability for a critical audience of 1000.

A reasonable starting point is a modern, well-maintained, 35-mm entertainment theater of 1000 seats. It is rare for picture or sound to be so poor today as to interfere in any material way with the enjoyment of the picture. Screens are designed to deliver the best picture practicable to the audience; sound equipment is as carefully designed to cover the complete audience with sound as the projection equipment and screen is designed to serve the audience with the picture.

If the raw film used for release prints for the 1000-seat, 35-mm theater is satisfactory for its purpose, the raw film used for 16-mm films to provide approximately equivalent picture and sound quality sound have 2.5 times the resolving power used for 35-mm. It is only in this way that the same detail, whether picture or sound, can be adequately rendered. The ratio represents the inverse ratio of the speeds of 90 ft. per

minute to 36 ft. per minute. Since the rated resolving power of 35-mm ordinary positive is 55 lines per millimeter, the resolving power required for equivalent performance in 16-mm would be 55 times 2.5 or 137.5 lines per millimeter. If practicable, this resolving power value should be considered the minimum to be used; every effort should be made to use materials of the highest resolving power available for the specific application.

Eastman Kodak has published a welcome book, "Properties and Performance of Eastman 35-Mm and 16-Mm Films for Professional Use," which aids in the selection of the various Eastman materials. The outstanding materials for black-and-white duplicating are Eastman 5203 for dupe negative and Eastman 5365 for master positive. Although 5203 seems somewhat shy of the objective of 137.5 lines per millimeter it is the best Eastman material available and it may be used to good advantage by using a rich, fresh developer.

Cost Factors in Use of Fine-Grain Film. Most 16-mm black-and-white prints today are being made on fine-grain film of rated resolving power of 90 lines per millimeter. These materials are slow photographically with respect to ordinary positive materials that were commonly used in the United States before World War II. When fine-grain materials were first introduced, DuPont, in referring to their 605 type 16-mm, fine-grain film, stated: " To date it has been impossible to get sufficient light for reduction printers to use this slow film for prints from 35-mm negatives." Such exposure problems have since been overcome for 90-lines-per-millimeter films, but they still remain if 150-lines-per-millimeter materials such as Eastman 5365 are to be used for release printing.

For commercial laboratory use at the present time, the use of a material such as Eastman 5365—a yellow-dyed master positive—for release printing in accordance with published data would be impracticable since it requires a developing time of 9.5 minutes in the recommended negative-type developing bath. The average commercial film laboratory cannot afford a developing time for release prints greater than approximately 4 minutes because of competitive pressure. In many laboratories, the customary developing time for release positive is about 3 minutes and may in extreme cases run as low as 2 minutes. As a matter of cost calculation, if we add the additional cost of the raw film to the additional processing cost, the resulting price increase would represent such a large percentage of present costs that most customers would prefer the 90-lines-per-millimeter material despite its technical shortcomings.

The problem of printing such materials as 150-lines-per-millimeter duplicating positive is more an economic than a technical one. As a temporary commercial measure, it is possible to use the same expedients as were used when the step was first made from 55- to 90-lines-per-millimeter materials. The following compensating steps must be taken in the proper amounts.

(*1*) Increasing the energy of the developer.

(*2*) Increasing the intensity of the light source of the illumination system and/or improving the efficiency of the system. This may mean the installation of a mirror at the rear of the lamp to re-direct the light flux from the rear to the aperture, or even the installation of a new type lamp such as a high-pressure mercury arc. Details of such changes are found in technical journals such as that of the SMPE.

(*3*) Reducing the linear speed of the film through the printing machine to increase the exposure by the proper amount.

Just how the compensating steps are to be apportioned is a matter of designer's choice. Regardless of the balance finally chosen, the cost of fine-grain printing and developing is going to be higher than that for the handling of coarser grained materials.

In general, it is desirable to keep the speed of printing sound track above 60 ft. per minute, if possible, even when very fine-grain films are printed. At higher printing speeds flutter is reduced compared to lower printing speeds in the same machine. If a step printer is used for printing picture, a reduction of the linear speed will not be a handicap to print detail but may actually improve it. It will be necessary in both cases to make certain that the air blasts used for cooling are adequate to remove heat sufficiently rapidly to keep film and machine temperatures at reasonable values.

Other Factors in Use of Fine-Grain Film. To get the most from fine-grain film requires "tightening up" of all operations. Not the least important of these is the reduction of the amount of dust, dirt, and foreign matter accumulated during processing. If 35-mm film can tolerate so many pounds of muck per thousand gallons of water or solution used, 16-mm fine-grain of equivalent quality can tolerate only 40% of that amount. If 35-mm can tolerate so many pounds of dirt per million cubic feet of drying air in the drybox of the developing machine, 16-mm fine-grain can tolerate only 40% of that amount. It is necessary to be meticulous in handling 16-mm, whereas ordinary care was satisfactory for 35-mm; it is necessary to be extremely careful in 16-mm if something more than ordinary care is needed in comparable 35-mm handling. The mag-

nification at which 16-mm projectors operate in practice is appreciably greater than the magnification of 35-mm projectors, and dictates this need for greater care.

It should be remembered that the characteristics of human vision are such that normal eyes are accustomed to sharp and well-defined images; the 16-mm film will perform its function most satisfactorily when the images provided by the film are comparable in sharpness with natural images. Today, we are using film materials with resolving power comparable to that of lenses of better grade 16-mm projectors, *i.e.*, 80 lines per millimeter at the center. The trend in projection is toward lenses with still better definition. To keep pace, the resolving power of release print materials must be increased still further. Experimental films with 100-lines-per-millimeter resolving power were available in 1931 when we were using 50-lines-per-millimeter materials; today 150-lines-per-millimeter materials are available now that we are using 90-lines-per-millimeter materials for release printing.

The technique of manufacture of the better materials is fairly well known. The problem is to prepare to process the material commercially, and to bring the price to lower levels, by making use of such materials the rule rather than the exception. This, it seems, is the next hurdle for the film manufacturers to overcome by providing less expensive materials, and for the progressive laboratories to overcome by adapting their methods to such materials.

There would seem to be little point to put forth a great amount of effort and go to great expense in the manufacture of fine-grain, dirt-free, raw film materials if their potentialities were not realized during subsequent processing. A very material quality loss due to loss of definition and an increase in dirt due to processing occurs when the average fine-grain film is processed today. These factors should be under continual observation and control. Much can be learned if a short test strip, such as that recommended in American War Standard Z52.3-1944, is attached to every edited original for control purposes. If this test strip is printed through in every duplicating and copying process so that it not only appears on the release print but also on every intermediate film, it becomes possible to obtain a qualitative idea if not a quantitative one as to the magnitude of the quality losses at each copying step. The collection of such data and their proper interpretation is capable of revealing just where "process tightening up" is required, and by what amount it is practicable. The result of such quality inspection in control improvement

cannot help but result in better prints at lower cost to the user with a better profit to the laboratory: the true objectives of any well-run, mass-production process.

It is impossible in a chapter as short as this to do little more than outline very briefly a few of the many important factors involved in laboratory operation. Each item of machinery alone would require many words and many illustrations to describe it and to show how the design compromises selected appear to be the most practicable for the intended application. The integration of the machinery and the personnel into a workable organization capable of turning out a good product at a competitive price is a subject that would require individual treatment for each specific situation. Broad generalizations would require too many qualifying limitations to be of great value.

Film laboratory machinery, while quite highly specialized, has all the disadvantages from the purchaser's viewpoint of any product that is not mass-produced. When purchasing, it is always necessary for a purchaser to rely upon his arrangements with a manufacturer's representative, since most of the literature describing machines is out-of-date, inaccurate, and incomplete. The purchaser must look into every small detail to assure himself that the machine or equipment that he proposes to order will fit his specific need. Even if equipment appears to fit the need quite accurately when first installed, it will often be found that modifications are required after it has been put into service. In addition, the equipment will need service and maintenance. For this reason, it will usually be necessary to have the facilities of a small machine shop available in the plant. In the larger laboratories there is also an engineering department with the specific function of designing and supervising the manufacture of the specialized machinery required in the laboratory. In this latter case, the machine shop may be large enough to manufacture, install, service, and repair substantially all the machinery used in the plant.

The quality of the release print is often determined in the film laboratory. To serve its purpose best, the release print, like any other manufactured product, should be made of the best materials and by the best processes. Only when it is so made is its attention potential—latent in the edited original—fully realized.

Selected Bibliography

For bibliographic material the reader is referred to the following indexes in the *Journal of the Society of Motion Picture Engineers.*

July 1916–June 1930

"Animation," page 117.

''Camera Accessories,'' page 119.
''Color Rendering in Black and White,'' page 120.
''Defects in Film Resulting from Processing,'' page 123.
''Development of Motion Picture Film,'' page 123.
''Drying of Motion Picture Film,'' page 124.
''Duplication of Motion Picture Film,'' page 124.
''Electrical Machinery and Equipment,'' page 125.
''Film, Damage to, in Use,'' page 127.
''Film Manufacture,'' page 127.
''Film, Photographic Characteristics,'' page 127.
''Film, Physical Characteristics,'' page 127.
''Film, Reels,'' page 128.
''Fixing of Motion Picture Film,'' page 128.
''Gelatin,'' page 129.
''Incandescent Lamp for Projection,'' page 134.
''Laboratories for Processing Motion Picture Film,'' page 134.
''Laboratory Apparatus,'' page 135.
''Lubrication of Motion Picture Film,'' page 135.
''Mechanical Accessories,'' page 135.
''Miniatures,'' page 136.
''Optics,'' page 137.
''Perforation,'' page 138.
''Photometry,'' page 139.
''Printers,'' page 140.
''Printing, page 140.
''Sensitometry, Methods, and Instruments,'' page 145.
''Silver Recovery,'' page 145.
''Sound Film Processing,'' page 146.
''Splicing,'' page 149.
''Static,'' page 150.
''Stills,'' page 150.
''Technical Motion Picture Photography,'' page 151.
''Tinting and Toning,'' page 152.
''Titles and Title Making,'' page 153.
''Trick Photography,'' page 153.
''Viewing Devices,'' page 153.
''Washing of Motion Picture Film,'' page 153.

January 1930–December 1935

''Animation,'' page 7.
''Apparatus,'' page 7.
''Applied Motion Picture Photography,'' page 9.
''Background Projection,'' page 10.
''Cleaning Motion Picture Film,'' page 12.
''Committee Reports, Laboratory Practice,'' page 14.
''Composite Photography,'' page 20.

1936–1945

CHAPTER XIII

Projection and Projectors

Introduction

It is difficult to treat the subject of projection and 16-mm projectors without some definite use objective in mind. The needs of projection in schools, for example, are different from the needs of projection as may be carried on in church halls, YMCA, and other semi-public and public buildings. Projection is in reality a means to an end and not an end in itself. In the case of the school classroom, the projection of 16-mm motion pictures must coordinate with other visual and audio media implying an integration with the school curriculum in general and with other visual-audio media.

Fortunately, the projection requirements of most forms of projection other than motion pictures tie in quite well with motion pictures. A matte-surface reflective screen should be used for maximum utility. As in motion pictures, the minimum distance of the nearest observer from the screen should be not less than 2.5 times screen width (2.5 w) and the maximum distance of the farthest observer about 5.5 times. The maximum distance that any observer may be located off the projection axis to either side is equal to his distance from the screen. As will be mentioned later in this chapter, these projection conditions will be found most satisfactory for motion pictures under reasonable conditions of room darkening.

Visual-Audio Media of a Classroom

Although the visual-audio media of a classroom are quite beyond the scope of this book, some mention must be made of them. The importance of the interlocking of their relationships is very great not only because of their number and variety, but also because the schoolroom affords an almost ideal opportunity for the useful employment of every kind of medium. All media are tools, and not ends in themselves; all are measured in terms of the improvements in learning rates that result from their use. As in any other situation in which tools are used, some tools are extremely

valuable in some cases, while the same tools may prove a handicap in others. The best tools for a particular case are those that provide the quickest and best results in terms of increased learning at the lowest cost.

Visual-audio media may be divided into two broad classes, nonprojection and projection. The older—and better known media—are the nonprojection media. These include:

(*1*) The blackboard—probably the best known and requiring no explanation.

(*2*) The display area—where charts, pictures, maps, posters, etc., are placed.

(*3*) The exhibit—material brought into the classroom. This may be a small-scale model of a machine being studied, or it may be merely samples of coffee, wheat, barley, rice, etc., should the classroom discussion revolve about such grains and foodstuffs of the world. An exhibit may be either permanent or temporary.

(*4*) The demonstration—a workshop adapted to the classroom. Typical are the first experiments in chemistry and physics performed by the instructor to acquaint the students with the techniques of handling such apparatus before they perform their own experiments in the school laboratory.

The projection media are newer than the nonprojection media; many of them received much impetus in the various war training programs of the U. S. Armed Services and of war production industries. The projection media include:

(*5*) The ''stills'' projection program—an extension of the blackboard, which, in turn, includes:

A. Transparency slides—usually 2 × 2 in. and 3 1/4 × 4 in.

B. Slidefilm—with or without sound—35-mm film usually about 100 frames long (7 ft.).

C. Opaque material—usually newspaper clippings, paper prints of pictures, etc., usually 6 × 6 in.

Projection of ''stills' can be accomplished on the same matte surface screen used for motion picture projection as previously described. Sound slidefilms are now very common; a 33 1/3-rpm, disk-reproducing turntable with associated amplifier and loudspeaker is part of the typical machine. At the end of the word commentary on a particular scene in the slidefilm, a recorded tone such as a gong sound or oscillator tone is provided. This tone may be utilized to effect a scene change automatically by advancing the film one frame, or it may act as an audible warning tone to the machine operator to advance the film manually. Where a recorded tone is used to effect automatic advance, the preferred tone is one of low frequency, *e.g.*, 30 cps, which is below the normal response range of the audio amplifier and loudspeaker used and is therefore inaudible to the audience.

An important advantage of the slidefilm over transparencies quite apart from its low cost is that the scenes of the film are certain to be projected in correct sequence.

To reduce the number of machines needed, a number of manufacturers have sought to combine two or more of these projection functions in a single mechanism. The most common combination is that of the 35-mm slidefilm and the 2×2 in. slide. Although this compromise need not involve a serious loss of optical efficiency because the image areas to be projected are not greatly different, the compromises that must be made if design simplicity is to be maintained become serious when an attempt is made to include the larger $3\,1/4 \times 4$ in. transparency. The compromises become very serious when the 6×6 in. opaque material function is also included.

When there is a material difference in the size of the transparency or opaque material to be projected, not only the projection objective lens but also the condenser lens must be changed in focal length if good light efficiency is to be achieved with all sizes. In the optical system, the light source is imaged near the aperture where the transparency or opaque material is located; the condensing lens system should adequately and uniformly illuminate the material without serious waste of illumination beyond its boundaries. The area of the light source is fixed, and a change in the focal length of the condenser system is required, just as is a change in focal length of the projection objective lens.

Admittedly, it is undesirable for a classroom to "bristle" with projection machines and audio aids when only one facility can be used at a time. Thus, as a practical matter, it is usually justified for the sake of operational convenience and simplicity to sacrifice illumination efficiency to some degree in a combination machine if the screen brightnesses of the facilities so furnished are not too widely different from one another.

The real problem, however, goes deeper. There is still much room for improvement not only in providing apparatus integrated with the teaching program (as well as the integration of the apparatus components with each other), but also there is a far more serious need for the improvement of teaching techniques by providing visual-audio materials using the most effective facilities integrated as a part of the teaching method and fitted accurately to the specific teaching need.

As one example, it is well known that the amount of "dwell" time needed for the contemplation of an important point varies from one audience group to another. One possible arrangement that can take this into

account is a composite 16-mm motion picture and slide or slidefilm machine which would be a "gearing-together" of the two mechanisms. When a "dwell" point is reached with such an apparatus, the motion picture projector would be cut off automatically, turning on the slide machine. When the instructor felt that the point had "sunk in" adequately, the push of a button would shut off the slide and continue the motion picture projector on its way once more.

There is no coordination or standardization among available mechanisms; this applies quite as much to audio aids as it does to visual aids. Fittings, connectors, loudspeakers, amplifiers, etc., are all made to perform as components of the specific machine or device only, with no attempt to eliminate duplicate functions among complementary machines. Visual-audio aids are very much needed; lack of integration is a serious factor in retarding their natural growth.

(*6*) Specialized projection which includes microprojection and the projection of vectographs in stereo projection.

Microprojection includes the projection of microscope slides illuminated by transmitted light and also the projection of dark-field illuminated objects by reflected light. For the teaching of subjects such as biology, slides may be prepared with familiar insects, flowers, etc., and shown with transmitted light. Rock samples and metal structure samples are commonly illuminated with reflected light. In general, microprojection should be used in every instance possible where the student will later use a microscope. The screen used for microprojection may be the same matte screen used for motion pictures.

Stereo projection, which made tremendous strides during World War II, is an invaluable aid in the visualization of objects in space. The teaching of geography, and especially topography, solid geometry, astronomy, navigation, map interpretation, and a host of other subjects is made more efficient and practicable and results in very material savings in learning time, and in increase of depth of comprehension. Stereo projection should be started at an early stage in a school career in order to familiarize the student with the visualization of things in space.

Since stereo projection is specialized, it requires an aluminum-coated screen (specularly reflecting rather than the more usual diffusing matte surface) that sharply limits the audience to a very narrow viewing angle, but a small fraction of that customary with the matte screen used for other kinds of projection. The viewing angle for stereo projection may be but one-third of the customary viewing angle.

(7) The motion picture projection program—which includes silent film as well as sound film. The primary need is for 16-mm. 35-mm is unsuitable because it is ordinarily hazardous, and the machines are bulky and complicated. 8-mm is rarely used except for locally produced films, since commercial teaching films are released almost entirely in the 16-mm size.

(8) Audio projection—which includes facilities for radio (conventional broadcast and frequency modulation), for playing disk and other records and transcriptions (78 rpm and 33 1/3 rpm*), for making and playing back local recordings (disk, wire, magnetic tape, etc.), and interconnection among classrooms such as in a centralized sound distribution system.

(9) Television projection—in color, and in black and white when such facilities become widely available commercially.

No attempt will be made in this chapter to go into detail with regard to the needs and functions of the eight media other than motion picture projection. Suffice it to say that all are specialized, and the integration of the apparatus and the functions into a minimum of apparatus and accessories is a study that requires and deserves much attention. The Committee on 16-Mm and 8-Mm Motion Pictures of the Society of Motion Picture Engineers is presently engaged with the problem of 16-mm film projection as a continuing matter and reports its findings on this subject from time to time. At present there is no technical or other responsible body that is charged with the responsibility of the integration and coordination of visual-audio aids into teaching programs in the manner in which the SMPE Committee is concerned with the 16-mm film projection problem.

Definition

A motion picture projector may be defined as a machine that appears to make images move when a suitable strip of film with a succession of suitable images is projected through it. Of course, the recorded images themselves do not move at all, but rather it is the eye of the observer that provides the illusion of movement when a succession of individually stationary images slightly different from one another is presented to the eye. Movement appears to occur because of the small differences from frame to frame along the film. Each individual frame must be clear and distinct and free from any trace of blur because it will be enlarged several hundred times when it is viewed. The film itself may be thought of merely as a series of sequential photographs spaced one twenty-fourth second apart if the film is projected at sound speed. A practical projector for this film does not merely project one frame after another; the projection cycle which will be described later is more involved so that

* And possibly 45 rpm.

flicker may be reduced to a minimum and picture brightness increased to a maximum.

Frame Size of Picture to Be Projected

There are 40 frames per foot of 16-mm film. As there is but one sprocket hole per frame, the nominal distance between adjacent frames is 12.000 in. per foot divided by 40 frames per foot, or 0.300 in. per frame.

Because film is dimensionally unstable and shrinks and swells during the various stages of its processing and use, and because of the errors in placement of the images and the weaves introduced by the various machines used that occur as a result of the inaccuracies of the guiding and propelling mechanisms in cameras, in recording machines, in printing machines, and in projectors, it is necessary to limit the height of the frame to be projected to some arbitrary value less than 0.300 in. This is accomplished in the projector by the use of an aperture at the film gate where light is transmitted through the film to the objective lens that focuses the image in the gate to the screen. The width of the frame is similarly limited for similar reasons.

The standard dimensions for the 16-mm projector aperture are 0.380×0.284 in. These dimensions are shown in Proposed American Standard Z22.8-1949 issued by the American Standards Association under the sponsorship of the Society of Motion Picture Engineers (Fig. 13). All American Standards in motion pictures are similarly issued and similarly sponsored.

Shape of Projected Picture

The shape of the picture projected on the screen depends upon the shape of the projector aperture. The standard aperture is rectangular; the aspect ratio (the ratio of width to height) is approximately 4 to 3. This picture aspect ratio is very widely used; it is used for:

(*1*) 35-mm motion pictures.

(*2*) 16-mm motion pictures.

(*3*) 35-mm slide films.

(*4*) Transparencies.

(*5*) Television—whether live pickup or transmission from still or motion pictures.

Size of Projected Picture

The size of the projected picture depends upon the working magnification provided by the projection machine under its actual conditions

of use. The working magnification in turn depends upon the focal length of the objective lens used in the projector and the distance of the projector aperture from the screen.

When an ordinary scene is photographed, the area of interest of the scene is reduced in size to fit within the camera aperture (Fig. 11)—0.405×0.295 in. (Proposed ASA Z22.7-1949.) Only a portion of this area—0.380×0.284 in.—is projected through the projector aperture; the remainder is cut off from view. The transmitted portion is enlarged in projection to several feet in width. With even a well-designed machine, an enlargement to 6 ft. in width, for example, requires an efficient optical system using an incandescent lamp of at least 750-w. rating if adequate illumination is to be provided for even the best matte screen. Most 16-mm sound projectors such as the Eastman, Bell and Howell, Ampro, Victor, DeVry, etc., use a lamp of 750-w. rating.

Even though provision is especially made to assure that the terminal voltage of each lamp is in strict accordance with its voltage rating, it will be found that significant differences in brightness and in image detail on the screen occur from one manufacturer's projector to that of another, and there are noticeable differences among apparently equivalent products of even a single manufacturer. In this regard, 16-mm projectors—whether silent or sound—are no different from any other manufactured product in their variability characteristics.

Perspective Considerations of Projected Picture

The perspective considerations of this section are applicable to the projection of 16-mm motion picture whether by reflection from a conventional screen, or by transmission through a translucent screen as is used in Trans-Lux and Panoram Soundies projection. The former type is in widest use, and most direct reference will be made to it.

It is usually assumed that the "average" 16-mm motion picture scene has been photographed with a lens of 1-in. focal length. The angular width (half-angle) of the scene is about 22°. When the conventional 2-in. projection objective lens is used, the correct distance of the observer from the screen is a little greater than 2.5 w and the projector distance from the screen is about 5.25 w.* Only at this position are both the foreground and the background of the picture seen in correct perspective; neither is foreshortened or elongated.

* w is the distance from the screen measured in screen widths.

It is rare that a lens of focal length shorter than 1 in. is used to photograph a 16-mm scene. Generally speaking, the 1-in. lens is used for the "establishing" or long shot that sets the locale for the action being portrayed. Lenses of longer focal length are often used for photographing the detail that appears in the medium shots and in the closeups. It cannot be blindly assumed that perspective considerations were thought of primary importance in the photographing of all scenes in an edited film. It is impossible to determine merely by screening a picture whether other practical considerations such as physical restrictions due to the nearness of a wall or other obstruction may have been the deciding factor in a particular scene. Very often a cameraman is influenced strongly by the fact that the commercial lenses of 1-in. focal length that he has on hand are of poor quality compared with his lenses of 2-in. focal length; he may rightfully prefer a "sharp" 2-in. lens to a "fuzzy" 1-in. lens. In addition he may feel that perspective is not of much importance.

Proper perspective cannot always be achieved even if its needs are known; under certain circumstances it must be definitely sacrificed if a picture is to be taken at all. In photographing wild animals, for example, one explorer has used a 9-in. lens simply because the animals would be frightened if the camera were at closer range. It is doubtful that these pictures were ever viewed with correct perspective by any audience. When a film is edited that has shots taken with the 9-in. lens cut into the same roll as establishing shots taken with a 1-in. lens, it becomes a question of definition as to what the "average" perspective of such a film may be. Valid arguments may be presented in favor of greater "weighting" of the scenes of long focal length; such scenes provide most of the detail. Other valid arguments may be presented in favor of "weighting" of the scenes in accordance with the length of the scenes. This might tend to lean in the direction of a shorter focal length as the "average." Such cases are special, however, and need be given small consideration. What is more important is consideration of more representative films. Much present-day photographing is accomplished with 1-, 2-, and 4-in. lenses; there seems to be a trend toward emphasis of the 2-in. lens over the 1-in. lens. It is difficult to determine the reason, but it is reasonable to hazard a guess.

The differences between that photographing for 35-mm entertainment films and for 16-mm films that are mostly of the nonentertainment variety, are often considered minor, yet a gap seems to be growing in photographing techniques. The change has been in 16-mm, with 35-mm films

remaining about the same with regard to perspective. In 35-mm films most of the scenes deal with people and have about the same kind of background with regard to size. 16-mm films, on the other hand, have been dealing more and more with small objects and less with people. The result with regard to perspective is a shift in the "average" scene from the 1- to the 2-in. lens shot. It is not unlikely that the shift will be even more pronounced in the future when the need for showing more and more detail of smaller and smaller objects occurs. It is not uncommon even now to fill a 6-ft. screen with the image of a 1-in. long 6-32 machine screw projected from a 16-mm print. This represents quite a magnification ratio and implies a long focal length for the photographing lens.

The "average" viewing distances found in 35-mm entertainment motion picture theaters seem to tend to be shorter than the "average" distances for 16-mm projection when measured in terms of screen widths. The maximum viewing range recommended by the Society of Motion Picture Engineers in the Non-Theatrical Committee Report of July 1941 was from 2 w as a minimum to 6 w as a maximum. In an incomplete study reported by another SMPE Committee, it was found that viewers seemed to prefer the range from 2 w to 4 w in a 35-mm entertainment theater of only 4.85 w in length.

During World War II, American troops who viewed 16-mm reduction prints of the Hollywood entertainment pictures apparently tended toward appreciably longer "average" distances, with reported audiences as large as 2000. With an audience of that size, it is probable that the most distant spectators were appreciably more than 6 w from the screen. It seems reasonable to believe that the influence of peripheral images around the screen was probably appreciably less in such projection than in the case of the average motion picture theater, giving due recognition of course to the fact that under such war conditions much larger attendances are common.

It is well known that the acuity of vision depends upon the angular location of the object being viewed with respect to the optical axis of the eye. For convenience, the field of view of the eye may be considered to be divided arbitrarily into a central portion where acute vision occurs, and the side portions where peripheral vision takes place. If attention is to be concentrated upon a central field of view, such as a motion picture screen, any movement of an object within the peripheral field will cause a viewer to turn his head instinctively in the direction of the moving object. A similar distraction occurs if dimly lighted stationary objects

are present within the peripheral field of view. The distractions caused by such images in the peripheral field will usually cause an observer to select a seat closer to the screen to reduce their effects. This prevents a choice of a location based upon the perception of perspective, the strongest link between the motion picture image and the reality that it represents.

In a planetarium, all sense of distance is lost to an observer because the objects viewed are for all practical purposes point sources in space that have no dimensions, and being dimensionless, can have no perspective. The illusion in a planetarium is lost if the dome of the planetarium from which the points of light emerge is noticeably illuminated with stray light.

In viewing a diorama, the sense of distance communicated to the observer is given by the perspective of the painting or photograph; the lighting of the surrounding wall and other space is nil or substantially so. This is accomplished by painting such surfaces with a dull black paint that absorbs stray light. When properly illuminated, there is nothing visible in the foreground between the diorama and the observer, and all sense of perspective can originate only with the painting. If other objects were revealed by stray light, or images were shown that "clashed" in perspective with that conveyed by the diorama itself, the viewing illusion would be impaired or destroyed.

To one who has seen dioramas and planetariums, it is difficult to understand why so little attention seems to be given to the perspective possibilities of the motion picture when it is often feasible to do so. In a planetarium or in a diorama, the field of the images of interest extends beyond the limits of the peripheral field of view of the eye, and the illusion of the continuity of the observed space is retained. The width of the motion picture screen, on the other hand, is quite limited, and yet it is possible to retain the illusion to a considerable degree if viewing conditions enable "knothole" viewing. The effect of such viewing can be gaged exerimentally if the observer will view a motion picture screen through a projection port of a motion picture booth in such manner that the port masks the screen image slightly on all sides. This simple experiment indicates quite forcibly the importance of peripheral viewing in the aiding or destroying of the perspective illusion.

In "knothole" viewing, the plane in which the distraction occurs, namely, the plane of the masked projection room port, is close to the observer's eye, while the plane of the screen is far from the observer's

eye. The distraction that may occur at the masked port is far out of the range of accommodation focus of the average eye, and the observer makes no instinctive attempt to slightly alter eye focus to determine what the exact nature of the distraction may be, since he realizes that to do so would necessitate putting the screen far out of focus. Since he chooses to concentrate on the screen, such a change in focus would require a conscious effort, rather than merely a subconscious readjustment—and therefore such minor distractions are ignored.

In the ordinary 35-mm motion picture theater, the screen is merely placed upon the stage adjacent to the plane of the proscenium arch, and neither far forward nor behind. The diffused light from the screen illuminates the area surrounding the screen, revealing details of form, color, etc., of such objects as the curtains and their ruffling, the stage floor, the proscenium arch, the decorations, and the side-stage lighting. The result of this arrangement is distracting, and tends to destroy the illusion conveyed by the film since the observer tends to select a shorter distance from the screen to reduce the distracting effects upon his peripheral field of view. The selection of the shorter viewing distance tends further to destroy the perspective illusion available in the film.

Where ruffled curtains and the like are dimly illuminated close to the plane of the screen, only a small change in focus and a slight twisting of the eyes or head are required to bring the attention-diverting activity into sharp view. As the eye is always watchful for movement within its peripheral field, the slight ruffling of a draped curtain caused by an air gust will cause a quick shift of the center of attention from the screen to the area of movement. Under such projection conditions, projected films lose much of their perspective potential and of their attention potential in the conventional theater, since the viewers' eyes tend to become jittery in anticipation of suspected movement within the dimly-lit peripheral field of view.

When 16-mm entertainment films were projected for troops during World War II, the screen was often set up in a cleared area with nothing visible near the screen on either side or to the rear beyond the screen. Under these conditions there were few distractions within the peripheral field of view, and the perspective portrayed on the screen was not seriously altered by its surroundings. Under these conditions, observers would tend to select a viewing location suggested by the correct viewing perspective, all other conditions being equal. It would seem that surroundings and their illumination play a very important part in the de-

gree with which the perspective portrayed in the film is conveyed to the audience.

A dark gray border should surround the screen; the use of a colored border should be avoided, particularly if color films are to be shown. As far as possible, there should be nothing distracting at the sides or to the rear of the screen. Admittedly, this is very difficult to accomplish in the extreme. Most motion picture projection is capable of material improvement, however, if these elementary considerations are taken into account and simple precautions observed.

In arranging facilities for projection—whether temporary or permanent—it is a theoretical objective to locate the audience uniformly about the center of correct perspective. Very few published studies have appeared that deal with viewing distances and their relations to perspective,

TABLE XXII

Viewing Distance for Correct Perspective *vs.* Focal Length of the Projection Objective Lens

Focal length, in.	Viewing distance for correct perspective, w	Focal length, in.	Viewing distance for correct perspective, w
1	1.8	3	5.3
1.5	2.6	3.5	6.1
2	3.5	4	7.0
2.5	4.4		

except where entertainment films are shown. Calculations that may be made at present cannot be considered reliable except in a very general way due to the wide tolerances probably present in most pertinent measurements. A thoroughgoing analysis of 35-mm entertainment films and of 16-mm films of various kinds is needed to reduce the large element of uncertainty now present. This would seem to be an excellent opportunity for the very practical application of theoretical statistics when sufficient data have been collected.

In its report of July 1941, the Non-Theatrical Equipment Committee of the Society of Motion Picture Engineers recommended 6 w as the maximum distance of an observer from the screen. Further studies indicate that it is likely that the maximum distance will be reduced in future recommendations, and may be as low as 5 w to permit better viewing of detail. The recommendation in the same report of 2 w as the minimum distance from a matte surface screen and 2.5 w for a beaded screen will probably be changed to not less than 2.5 for both cases for the purpose of

reducing the eyestrain that results from short viewing distances when a projector with the customary single-direction shutter is used. If a 2-in. projection lens is used, it is not unreasonable to believe that the viewing distance for correct perspective for 16-mm films of nonentertainment variety will will be nearer 3.5 *w* than 2.5 *w*. Based on this assumption, Table XXII indicates the viewing distance for correct perspective when projection objective lenses of different focal lengths are used.

For most uses, the 2-in. projection lens should be used, since the perspective that results is best fitted to the audience distances recommended. Unfortunately, many 2-in. projection lenses are of poor quality; the images are rarely sharp all over the projected field. The common defect is that the image is fuzzy at the corners when it is set for sharp focus at the center, and vice versa. To test such a lens, project a film of known quality. Suitable films are available through the SMPE.

Picture Detail and Its Relation to Observer

At conventional screen brightnesses, the average eye is capable of distinguishing detail represented by 1 part in 2000, or approximately 1.7 minutes of arc. At the distance *w* from the screen, the just discernible detail is 2000 lines per millimeter divided by 10 mm (the approximate width of the film gate) or 200 lines per millimeter. At other distances from the screen, the detail observable is equal to 200 lines per millimeter divided by the distance measured in screen widths. This data may be set up conveniently in table form (Table XXIII).

TABLE XXIII

Observable Detail *vs.* Viewing Distance

Distance from observer to screen, *w*	Average maximum observable detail[a]	Distance from observer to screen, *w*	Average maximum observable detail[a]
2	100	4.5	44
2.5	80	5	40
3	67	*5.5*	*36 (working limit)*
3.5	57	6	33
4	50		

[a] Measured in lines per millimeter at the film gate.

Magnification

When a scene is photographed on 16-mm film, the area of interest is reduced in size so that it may be properly accommodated within the pro-

jector aperture. When an image so photographed is projected, the image is enlarged, resulting, very often, in a projected image appreciably larger than the original object. This is particularly true of many closeups.

A 16-mm image is so small that the average unaided eye is incapable of distinguishing the fine detail in it. To make such small images convenient to view, they are enlarged in projection. In the case of a screen 6 ft. wide (a common size) the magnification in projection is equal to the screen width (in inches) divided by the projector aperture width (in inches), or 72 divided by 0.384; the ratio is 190. Such magnification is common with 16-mm projectors using a 750-w. lamp. (The screen illumination will be somewhat low when this magnification is used with the average projector.)

When a projector with a suitable light source such as an arc lamp is used, a screen 12 ft. wide can be filled comfortably. Ordinarily, such projection requires approximately 35 to 50 amps. for the arc to provide adequate light output with an efficient arc lamp. This latter case represents twice the magnification of the previously cited example, or 380. With really high-grade lenses, film, equipment, and operation, the quality of projected picture leaves very little to be desired in comparison with conventional 35-mm picture projection under comparable conditions of screen illumination.

Screen Brightness

If a motion picture is to be viewed properly, the screen must have the correct level of illumination in foot-candles in order to provide the correct level of reflected light in foot-lamberts. For 35-mm motion pictures, the ASA Standard Z22.39-1944 "Screen Brightness for 35-Mm Motion Pictures" requires that "the brightness at the center of a screen for 35-mm motion pictures shall be 10 plus 4 minus 1 foot-lamberts when the projector is running with no film in the gate." A conventional projector using a 750-w., 25-hour-life lamp should have a light output, if excellently designed, of 275 lumens; the minimum acceptable should be 200 lumens. At this light level and efficiency, the projector will have 10-foot-lamberts output if the reflection factor of the screen used is about 70% with the screen about 5 ft. wide. If a 1000-w lamp of 10-hr. life is used to replace the 750-w. lamp in a properly designed system, the light output of the projector will be increased to 385 lumens and the screen width may be increased to about 6 feet. To determine the lumens output required

from a projector for any desired screen brightness, the following formula may be used:

$$\text{Lumens required} = \frac{\begin{array}{c}\text{Desired brightness}\\\text{(in foot-lamberts)}\end{array} \times \begin{array}{c}\text{Area of screen}\\\text{(in square feet)}\end{array}}{\begin{array}{c}\text{Reflection coefficient of screen}\\\text{(expressed as a decimal)}\end{array}}$$

The light output mentioned above represents about the best obtainable from present designs, with most commercial machines falling short of the above performance by varying amounts. All manufacturers are prepared to guarantee the lumens output of their machines under specified conditions. It is well for a purchaser to obtain the information concerning the machine he proposes to purchase as a part of the manufacturer's guarantee of performance.

Although screen brightnesses as low as 5 foot-lamberts are considered passable, really good performance requires brightness in the order of 10 foot-lamberts, which will match quite closely the brightnesses found in 35-mm motion picture theaters. Table XXIV shows the required output

TABLE XXIV

Lumens Required for Different Screen Sizes with Light Level of 10 Foot-Lamberts

Screen width, in.	Lumens output required	Screen width, in.	Lumens output required
40	119	84	525
50	186	114	977
67	334	138	1410

of a projector in lumens for a number of different sizes of screens having the usual 70% reflection factor as is applicable to a used matte screen in good condition. In all cases, the height of the screen is three-quarters of its width.

Higher rather than lower screen brightnesses are desirable for the projection of Kodachrome and other integral tri-pack positives. There is much more detail in the shadows of Kodachrome dupe prints than in the highlights; for this reason somewhat higher screen brightnesses for such film is preferable to the more customary overexposure of the color duplicates that is resorted to by the film laboratory for the purpose of obtaining better projection with inadequate screen illumination from the projector.

As can be seen from the table, a 750-w. projector cannot be expected to do more than fill a 6-ft. screen. If a larger screen is to be filled, an

arc projector is required. Properly designed arc projectors are available that can deliver over 1000 lumens, and are suitable for a screen of approximately 10 ft. in width.

Projection Objective Lenses. The subject of lenses is an extensive one that usually requires many words and many figures if it is covered thoroughly. As the subject will be discussed here, no attempt will be made to cover lens design *per se*, the practical considerations concerning lenses available on the open market are more useful to most who will read this book.

There are numerous properties of a lens that should be checked by a purchaser. For all properties except resolving power there is no simple accepted standard method of testing. Fortunately, resolving power is the one property that needs most careful checking. The following are the other properties:

Chromatic Aberrations. This may be detected by the presence of a colored haze visible in the details over the whole field. Fortunately this is not a common defect.

Lateral Color. This is detected by the presence of one-sided color fringes appearing in the outer parts of the field and disappearing completely in the center.

Distortion. This is detected by straight lines in the outer part of the field appearing as curved lines on the screen. The straight sides of the picture gate of the projector itself make a good test.

Haze. This is detected by the presence of a misty haze of light covering the image without seriously interfering with the resolution. This is evidence of a large amount of spherical aberraton; lenses showng this defect should not be used.

The tests for all these is the projection of a good reference film. If any one of the defects as described is apparent to a person viewing the screen, the lens should be rejected.

Most 16-mm projection objective lenses—especially those of 2-in. focal length and of $f/1.6$ relative aperture—have a decidedly curved field, and the amount of curvature varies markedly among different manufacturers and among different lens types. Unfortunately, the manufacturers that make the most desirable machines do not ordinarily supply the best lenses. Resolving power measurements may be used as a criterion of the detail-rendering quality of a lens and of its flatness of field in a manner similar to the resolving power measurements of film. To obtain data for comparison, it is necessary to decide upon a specific procedure for testing, since the setting of the lens along the optical axis for best focus at the center of the picture is very often different from its setting for best focus at the corners. Ordinarily, it is desirable to focus for best sharpness at

the center of the picture and to make no readjustments when readings are made in the corners or elsewhere.

In all likelihood, 70% or more of the 16-mm projection objective lenses in use are of the 2-in., *f*/1.6 variety. In a typical lens of this class (made by Bell and Howell and tested in 1941), the resolving power measured 100 lines per millimeter at the center of the field, and was less than 20 lines per millimeter in the corners of the field. Such a lens, when sharply focused at the center, is very fuzzy at the corners; when rotated slightly to focus sharply at the corners, the center loses a major percentage of its resolving power. Operators using such a lens "split the focus" (as they call it) and focus most sharply at some indeterminate point intermediate between the two settings. Such a lens is bad, since the quality of the projected image varies over an excessively wide range because the operator cannot focus twice at the same point. Slight changes in focus adjustment are usually required with even the best projectors after the machines have warmed up, and although the picture may be satisfactorily sharp at the start, it will be very difficult to make readjustments of focus setting satisfactorily while the film is running.

It is not necessary for lenses to have such bad geometric distortion. A very good lens type such as the Bausch and Lomb 35-mm Super Cinephor projection objective lens is quite satisfactory at all parts of its field; it is quite large in diameter compared with 16-mm projection lenses of comparable rating. Incidentally, its price is about $150, while the price of the Bell and Howell lens previously mentioned was only about $15. Needless to say there have been considerable improvements in the quality of 2-in. *f*/1.6 Bell and Howell projection objective lenses, but it is still imperative for a purchaser to test a lens carefully before accepting it.

Designing a good 2-in. lens of wide aperture is not a simple matter and manufacturers have chosen different design compromises resulting in price differences and performance differences. One group of manufacturers has chosen to retain the same number of lens elements and to increase the resolving power in the corners by lowering it somewhat in the center; this has been characteristic of many of the lenses supplied by Ampro, Victor, and RCA. Other manufacturers such as Eastman have added an extra lens element, a field flattener, which materially improves the flatness with relatively little sacrifice of resolving power at the center.

As an illustration of the differences in resolving power (in lines per millimeter) to be expected when different focus adjustments are made or

an element added, the Bell and Howell lens previously mentioned showed the following on test (Table XXV):

TABLE XXV

Resolving Power Data for a Commercial 2-Inch $f/1.6$ Lens Compared with an Acceptable Reference

Conditions of use	Position of measuring of test pattern[c]			
	A	B	C	D
	Resolving power, lines per mm			
Focused at the center	100	60	30	< 20
Refocused (same lens)	50	70	30	20
Field flattener added[a]	90	80	60	40
Acceptable reference[b]	90	60	50	40

[a] These readings indicate a good lens.

[b] Agreed upon as desirable for Military Model Projectors according to American War Standard Z52.1.

[c] For position data, refer to "Non-theatrical Report," *JSMPE, 37,* 22 (July (1941).

There are no standards for 16-mm objective lenses. From the purchaser's point of view it is unfortunate that manufacturers do not provide test data in connection with the lenses sold with their machines. Without special test equipment, the best that a user can do to test a lens is to project black-and-white titles or to make a special lens-testing setup that utilizes the ASA Z22.53-1946 standard glass test plate. (This test plate is available through the SMPE.) Since projection lens quality is still generally quite poor, a buyer should make it clear to his dealer at the time of purchase that he wishes to test the lens supplied with the machine and proposes to return it should it prove poor when tested. When titles are projected from good film, the lens should be rejected if there is any evidence of lack of sharpness at any point in the projected field.

Most lenses, including Bell and Howell, Victor, Ampro, RCA, DeVry, and others, may be interchanged on projectors. The Eastman Kodak lenses are made with different lens mounts, and may be used only on Eastman projectors. It is unfortunate that Eastman lenses do not have the same mounting as other lenses, since they are among the "best buys." We can hope for some standardization action to be taken through the Society of Motion Picture Engineers, and through the American Standards Association to remedy this situation. Correction of a similar difficulty is already under way in connection with camera lenses.

Projection Systems. There are two systems of 16-mm projection in current use, projection by *reflection* from a screen, and projection by *transmission* through a ground glass screen or equivalent. The former is most common, representing most commercial projection equipment. In this system of projection, the projector is located near the rear of the projection space, with the light beam from the machine passing over the heads of those along the center line of the audience until it impinges upon a reflective screen. The arrangement is quite like that used in most conventional motion picture theaters.

The latter system of projection involves projecting directly on a ground glass screen or its equivalent from a projector located behind the screen. In an auditorium set up for this system of projection (as is found in certain Trans-Lux theaters) the audience views one side of the ground glass screen while the projector throws light on the other. This system of projection is used in 16-mm film "jukeboxes" such as the Panoram Soundies machines made by the Mills Novelty Company.

Although the reflective system is used almost to the exclusion of the transmission system in most applications except jukeboxes at the present time, some attention should be given the transmission system because of its excellent possibilities in retaining viewing contrast of the subject matter despite high ambient illumination levels. Although most of the practical problems in transmission projection still remain to be solved, operation with high ambient light levels may be accomplished with a screen that absorbs most of the light incident upon it. The general method that has been used experimentally in television receivers where a similar problem of high ambient illumination is encountered utilizes a neutral density filter with, *e.g.*, 90% absorption. The light transmitted from the projector is then 90% absorbed and 10% transmitted; the ambient light must pass through the filter twice in order to be reflected and is accordingly cut down to less than 1% of its incident value. The overall result is remarkable, particularly at the high ambient illumination levels often present in a classroom. Some form of polarizing filter may be used to supplement or replace the neutral density filter in the projection system to reduce the light losses. In addition, the screen may be designed to provide a certain amount of specularity if the projection angle required is narrower than usual. The principle of projection by transmission has been widely used in many of the "daylight" signs found in railroad terminals, etc. In the development of improved arrangements, methods should be used that will not be color-selective; projectors

must be designed to function satisfactorily with both black-and-white and color films. Much aggressive investigation of the screen problem is going on in television, and, when the results are directly applicable to motion picture projection, there is little doubt that such screens and arrangements will be marketed.

Reflective Screens. The purpose of a reflective screen is to reflect the light projected upon it by the projector. Screens, like anything else, become dirty and lose efficiency very rapidly with even an almost imperceptible coating of soot or dirt. The worst conditions that may be encountered are found in schools in smoke-ridden areas such as Manhattan in New York or the Mill district of Pittsburgh. The rate at which soot, dirt, and dust are deposited is really alarming to anyone who lives in a nonindustrial section of the country. When soot filters into a classroom, the motion picture screen, of course, acquires its full share.

There are two practical measures that may be taken to limit the loss of efficiency of a screen due to dirt collection:

(*a*) Wash the screen.

(*b*) Use a screen mounted on spring rollers, pulling it down when it is to be used, and keeping it rolled up when not in use.

Although both measures are quite simple, it is surprising how often these simple precautions are ignored, or their purposes defeated. The starting point is the purchase of the correct screen type. There are three broad classes of reflective screen:

(*1*) The diffusive or flat-white.

(*2*) The semidiffusive.

(*3*) The beaded or specular.

The semidiffusive and the beaded types ordinarily cannot be washed readily; the greasy sootlike deposit that collects on the screen infiltrates among the glass beadlike particles and cannot be removed without injury to the screen. The diffusive type can be made washable, but many diffusive screens are not washable. All three types can be spring-roller mounted without much difficulty, but it is necessary to make certain that frequent rolling and unrolling of the screen does not cause the screen to crease or streak, or to cause coating material to be removed or marked. A vacuum cleaner is effective in removing ordinary dust, but is rarely effective against greasy, sootlike dirt.

Screen makers can provide data concerning the washability of their products; without specific information, it is well to assume that a screen is not washable. All screens yellow with age; the amount and rate of

yellowing and spotting varies from manufacturer to manufacturer and from product to product. Screens are coated with paintlike materials, and the yellowing and spotting is comparable to that of paints. An excellent guide in the purchase of a screen is ASA War Standard Z52.56-1945 that was dropped at the end of the war.

A screen that appears dark when compared with a sheet of clean white paper should be replaced, since it is wasting one-quarter or more of the light incident upon it. A yellowish screen should not be used, especially for color films. It is also bad practice to continue to use a screen after it has acquired a mottled appearance. It is impossible to view a motion picture with satisfaction when a splotchy pattern of lights and shades due to the mottling is superimposed on the lights and shadows of every scene.

A definition of screen "whiteness" is found in American War Standard Z52.45-1945, and specifies that the ratio of the lowest to the highest reflection factor for any wave length between 420 and 700 $m\mu$ shall be at least 85% ; it also specifies among other things the performance requirements for a screen after aging as well as the method for making the artificial aging test.

The choice among the diffusive, semidiffusive, and beaded types of screens depends upon conditions of use. When the ambient room illumination is low (below 0.1 foot-lambert), and there are no sources of extraneous light, such as light "leaking" in through a doorway, between a drawn shade and a window frame, stray light bulbs, and the like, the diffusive or flat-white screen is without doubt the most satisfactory. This is a matte-type surface obtained by painting a wall with flat white paint or treating a fabric or rubber base material to reflect light in a similar manner. Such screens reflect the light that falls upon them in such manner that their brightnesses at all angles of view are approximately the same. A picture projected on such a screen is almost as bright when viewed from an angle of 30°, or even from an angle of 60°, as it is when viewed along the perpendicular to the screen. The reflecting ability of screens in different directions is customarily expressed in terms of a theoretical screen which reflects all light falling upon it in such a manner as to be equally bright at all viewing angles. Taking the coefficient of such an ideal screen as 100% in every direction, a good matte surface screen will have a reflection coefficient of about 85% along the axis perpendicular to the screen and 75–85% at an angle of 30°. The matte or diffusive screen is the type that should be used for the largest audience;

it is suitable for viewing distances of 2 w to 6 w, and for viewing angles up to 30° on either side of the axis perpendicular to the screen. For a person sitting at the side of the viewing space, it is the only screen type that provides least viewing discomfort because the ratio of the light reflected from the near part of the screen to that from the far part of the screen is not large. It is the only screen suited for viewing angles greater than about 20°. Typical reflection factors are given in the comparative table (Table XXVI) showing all three types.

The semidiffusive screen is more directional than the diffusive screen but less directional than the specular type. The semidiffusive screen, which may also be called the semispecular screen because its properties

TABLE XXVI

Reflection Characteristics of Typical Screen Surfaces

Angle of observation, degrees	Percent reflection		
	Matte	Semidiffusive	Specular (beaded)
0	93	250–430	550
5	91	240–400	345
10	88	220–310	240
15	85	180–220	155
20	82	140–150	94
25	80	95–105	70
30	79	70– 80	58
35	77	50– 60	53
40	76	35– 50	50

are intermediate between the diffusive screen and the specular screen, is usually an aluminumlike surface screen that exhibits on-axis apparent reflection coefficients of 250% for those rough in texture and up to 400 to 550% for those smooth in appearance. The properties of such screens are not accurately classified by name; they require curves to describe them. Aluminum-surfaced screens that appear to be smooth in texture often approach specular screens closely in performance. Aluminum-surfaced screens that appear rough in texture approximate the diffusive screens more closely in performance.

At this point it may reasonably be asked why specular-type screens such as the customary beaded screen are undesirable. The answer is found in their nonuniformity of light distribution. It is unfair to an observer at the side of the viewing space to provide a picture that is only a fraction as bright as the picture provided for the observer in the

center aisle. It is undesirable for a single observer to see the top of the screen with appreciably lower brightness than he sees the bottom of the screen. It is similarly undesirable to see one side of the screen with appreciably lower brightness than the opposite side of the screen. Although no standard has been promulgated with regard to brightness ratios, it has been suggested by the Non-Theatrical Committee of the Society of Motion Picture Engineers in their July 1941 report that the ratio between the brightest part of the screen and the darkest part of the screen should be not greater than 3 to 1.

A practical working standard for comparing apparent reflection coefficients is a freshly scraped block of pure magnesium carbonate, which is used very widely as a reference not only in connection with the measurement of apparent reflection, but also in connection with measuring the whiteness of screens and as the working standard material for photoelectric spectrophotometers. Blocks of this material may be obtained from scientific supply firms such as Central Scientific, Eimer and Amend, and others.

American War Standard Z52.46–1945 for "Brightness Characteristics of Projection Screens (Semi-Diffusing Reflecting Surface)" specifies that the brightness ratio at a viewing angle of 1.5° shall not be less than 80%, and not less than 65% at any viewing angle between 1.5° and 60°. Although the specification describes this screen as semidiffusing, its characteristics approach the diffusive screen much more closely than either the specular or the beaded screens.

The beaded screen has a surface covered with small glass beads or glasslike particles which reflect light internally, and at the same time direct the light back by refraction in such a manner that the largest proportion of the light is sent back in the direction from which it came. This is true even when the light strikes the screen at an angle. Since the beaded screen sends most of the light back toward the projector, that part of the audience sitting along the centerline of the viewing space sees a much brighter picture than would be provided by even the perfectly reflecting theoretical screen described previously. Values as high as 550% are common for such screens; a value of 180% (3 to 1 brightness ratio) is reached at an angle of only 12° or 13°; this represents the maximum viewing angle recommended. The performance differences among beaded screens of different makes are quite small.

Screens of the metallic type are not recommended for conventional projection, being suited primarily for stereoscopic projection with polar-

ized light. For most purposes, beaded screens are likewise to be avoided. The only screen recommended for general use is the diffusive type, which is fully satisfactory only if the ambient light level in the viewing space is 0.1 foot-candle or less. Where extraneous light does enter a viewing space, a beaded screen is advantageous if most of the audience is located along the axis between projector and screen. In this case the nearest viewers should be located no closer to the screen than 2.5 w, and viewers farthest to the side should not be located more than 12° from the central axis.

Distance of Projector from Screen

The distance of the projector from the screen may be calculated readily if the focal length of the lens is known. To account for all possible sizes of screens, Table XXVII is given in terms of screen widths.

TABLE XXVII

Projector Distance *vs.* Focal Length

Focal length of projector, in.	Projector distance, w	Focal length of projector, in.	Projector distance, w
1	2.65	3	7.95
1.5	3.98	3.5	9.28
2	5.30	4	10.60
2.5	6.66		

Uniformity of Screen Illumination

Illumination on the screen should be free from objectionable bands or patches differing in color or brightness from the adjacent parts of the screen. The average illumination at the four corner points should be not less than 65% of the illumination at the center. At no corner should the illumination be less than 50% of the illumination at the center. Better grade projectors in good adjustment can ordinarily meet this requirement.

The Projector

The 16-mm sound motion picture projector is in reality two separate mechanisms combined within a single assembly, one mechanism for the projection of picture and one for the projection of sound. It is the projection of picture that is of interest at the moment.

Figure 108 shows a typical 16-mm sound projector. "A" is the feed

reel upon which the unused portion of the film is carried. "B" is the feed sprocket which rotates at constant speed while pulling film from the supply reel and also maintains a free loop of film just ahead of the picture gate "C". At the picture gate the film is held in proper position for projection; within the film gate is the projector aperture through which light passes on its way to the screen via "D" the projection objective lens after passing through the picture image of the film. The film leaves the picture gate below the movement claw located near the aperture, and another free loop is formed before the film enters the

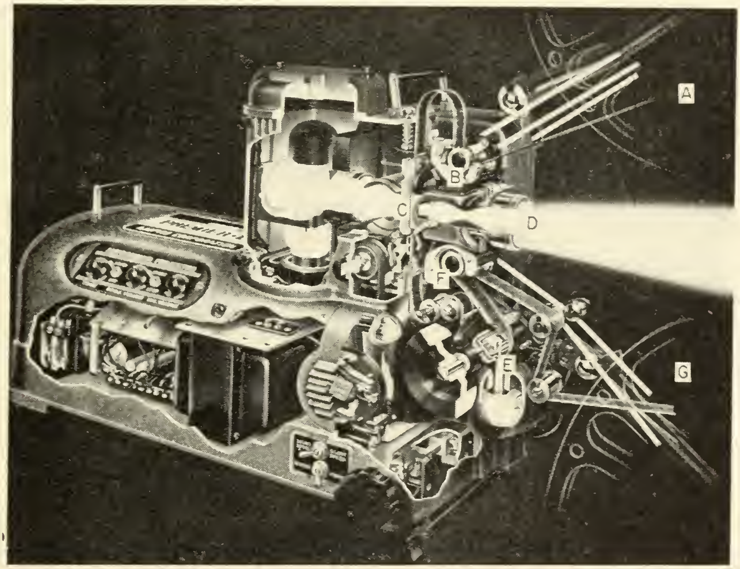


Fig. 108. Typical 16-mm sound projector (Ampro).

transport system of the sound translating portion of the machine. Part way through the sound transport system, the sound track on the film intercepts the sound light beam at "E". The modulated light beam is directed to the surface of a photoelectric cell for the translation of light variations into electrical currents and for subsequent amplification and translation into sound by a loudspeaker. "F" is the takeup sprocket which rotates at constant speed just as the feed sprocket does, and pulls the film through the sound transport system. "G" is the takeup reel on which the film is wound after it has passed through the machine. A 750-w. incandescent lamp is the customary light source for picture pro-

jection in most machines; a 6-v., 1-amp. lamp or a 4-v., 3/4-amp. lamp is the common light source for the sound light beam. The 750-w. lamp is customarily energized directly from the mains, either alternating or direct current. The sound exciter lamp is usually energized from a supersonic electron tube oscillator that is built as a part of the audio amplifier assembly. The oscillator operates at a frequency of about 15 to 25 kilocycles. This arrangement of the supply for the sound exciter lamp minimizes a.-c. hum without the expense of heavy rectifiers and filters, or batteries.

The film is moved through the film gate by the movement claw with an intermittent motion, and a new frame of film enters the projector gate every 1/24 second when the machine is running at sound speed.

In the optical system of the picture portion of the projector, a lamp (usually 750 watts) directs light to the aperture of the gate through a set of condenser lenses. To the rear of the lamp in the lamp house is a small mirror that redirects the light falling on it to the aperture, increasing the aperture illumination. The projection objective focuses the film image in the aperture to the screen. All optical elements are customarily aligned along a straight-line optical axis. Lenses, the mirror, and the gate should all be accessible for ready cleaning because the efficiency of the projector is seriously impaired by even small amounts of dust and dirt that are picked up in a short time by the projector.

Projector Mechanism

In a modern 16-mm projector, the motion of changing from one frame of film to another at sound speed takes but one-ninth* of a movement cycle of 1/24 second. 1/24 second includes both the periods of film movement and of rest. Some of the older models of projectors had a longer movement period amounting to one-sixth of a movement cycle, but were not capable of as bright a picture as the one-ninth movement cycle machines due to the fact that light could be theoretically available on the screen for a maximum of five-sixths of a cycle, whereas with the one-ninth movement cycle type the light could be theoretically available for eight-ninths of a cycle.

The intermittent motion is accomplished in most machines by a 2- or 3-toothed claw that enters the perforations of the film and withdraws from them, moving the film through the gate one frame at a time. The motion of the claw is usually produced by two synchronized cams. One

* Approximate value.

of these moves the claw in and out of the perforations, and the other advances the film one sprocket hole spacing—about 0.300 in.—at a time. The intermittent mechanism of the projector is a critical part, since imperfect functioning may cause pictures to jump on the screen, excessive wearing of the film, tearing of the perforations, and losing of the loop below the picture gate with consequent serious film mutilation. A 3-toothed claw is to be preferred to a 2-toothed claw because of the better chance of a film with a damaged perforation going through the film gate without interruption. Because of the complexity of the motions of the intermittent parts of the machine, such parts may wear very rapidly and lose their accuracy of movement if poorly designed, poorly manufactured, or made of unsuitable materials.

It is necessary that the light beam from the projector be cut off while the film is moving through the film gate. This is accomplished by a simple rotating sectored disk, called a shutter,* that is rotated by the projector gear train in synchronism with the movement claw of the film gate. Most shutters cut off the light between the projection lamp and the film gate, thereby eliminating heating of the film while it is in motion. The shutter interrupts the light beam not only while the film is being moved through the gate, but also when the film is stationary in the aperture. This latter interruption occurs for the purpose of reducing flicker, which would be intolerable if the additional light interruption did not occur. At conventional brightness, machines designed for sound projection speed (24 frames per second) and for combinations of sound speed with silent speeds provide two interruptions per frame, one during the film-moving period and the second during the period when the film is stationary in the aperture. Machines designed for silent speed alone (16 frames per second) are preferably designed with three interruptions per frame, one during the film-moving period, and two during the period when the film is stationary in the aperture. To obtain the maximum amount of light from the projector lamp, manufacturers seek to keep the light on the screen as long as possible consistent with minimum flicker. Incidentally, when the film is stationary in the aperture but the light is cut off, the movement claw moves downward, being actuated

* To reduce flicker still further, 35-mm machines of recent design such as the Simplex E-7 have two rotating shutters, one between the lamp house and the aperture, and the other between the objective lens and the screen. With such shutters, the image may be said to be swept on the screen in one direction, and off the screen in the other. Light efficiency is improved and flicker reduced compared with the single-blade shutter type.

by one cam, but the second cooperating cam does not permit the entry of the claw into the perforations. As a result the film does not move. This type of claw movement is referred to in the trade as a "skip" movement.

The single-blade shutter used in 16-mm machines harks back some 40 years or more in its design; no doubt the study given to the flicker and the brightness characteristics of television systems should soon begin to react favorably upon the design of 16-mm projection transport systems. Flicker and brightness characteristics of 16-mm projectors are deserving of much intensive study, since, as one possible means of improving light efficiency and reducing flicker, it would seem that the fade-in and fade-out dissolving technique might be applied in shutter designs to eliminate the abrupt light interruption that occurs while the film is stationary in the aperture. Something of this sort has been accomplished with continuous projectors. These machines of the rotating prism type have been best suited to projection with objective lenses where long focal lengths are necessary. Appreciable increases in illumination and reductions in flicker are possible with a fade-in fade-out design. As commercial 16-mm sound quality improves, it should be possible to obtain relatively high light efficiencies and very low flicker with reduced film speeds (say, 16 frames per second) should this seem desirable as a cost-reducing measure in the future; this would seem applicable, especially to high-quality silent projectors.

The sprockets, sprocket guards, and rollers of the projector should be designed to cause minimum wear and tear on the film. One important requirement is that the film shall be supported at all points in its path through a machine only at the safety areas of the film. A safety area is any portion of the surface of the film that does not bear picture image that is projected or sound image that is scanned. One safety area occurs at the sound track edge of a sound film, another occurs between the sound track and the picture, and the third occurs around the sprocket holes. When film wraps around a sprocket, it may either be pulled around or it may be kept in place by a film guard. The pulling method appears to produce the least film damage in commercial designs.

The film gate usually consists of two main plates, one attached to the body of the machine near the lamp and the other a movable pressure plate that is pressed against the body plate by means of springs. Gate pressure is usually adjustable; incorrect gate pressure either materially reduces film life or it results in a jumpy picture. Gate pressure should

be great enough to hold the film flat in the aperture when it is stationary, yet small enough to permit the film to be moved readily when the claw propels the film through the gate. The surfaces of the body plate and of the pressure plate are relieved or undercut so that only the safety areas of the film bear upon the cooperating plates. A good projector has all support parts (*e.g.*, sprockets, rollers, transport parts) relieved so that the film is supported only at the safety areas. A loop of film will go through a well-designed projector as much as 5000 times when a good machine is in good order, but less than 100 times in the case of a reputable machine that is poor by comparison. After 1000 times, such a loop should show little or no scratch or abrasion marks at those parts of the picture that are projected and at those parts of the sound track that are scanned by the sound light beam. To reduce wear to a minimum on the working parts of the surfaces of the sprockets, gates, and rollers the parts are made either of materials with excellent resistance to abrasion, such as stainless steel, or of softer materials such as brass or steel and are chrome-plated. In either event the parts are highly polished to reduce wear and abrasion of the projected film to a minimum. All rollers should turn very freely, since a roller that binds causes more film damage than no roller at all.

The sound translation system, although usually relatively simple, deserves special discussion and will be treated later.

The takeup reel is rotated either by the projector motor through a belt drive or by a separate motor. In either case there is some form of friction clutch or variable-speed drive between the takeup spindle that holds the takeup reel and the member from which the spindle is driven. There is no fully satisfactory takeup drive on any regular commercial machine that takes up very smoothly and with neither excessive tension nor too slack tension for all portions of all commercial reels from the inside of a 200-ft. American War Standard reel of 2-in. inside diameter to the outside of a 2000-ft. American War Standard reel of 15-in. outside diameter. It is entirely too much to expect of a simple friction clutch that is to be reliable and cheap to manufacture, to operate over a torque radius range from 2 to 15 in. With almost any commercial projector that uses 400-ft. reel—even the American War Standard 400-ft. reel—cinching will always be present on the first 25 to 50 ft. because of excessive takeup tension. The practical solution to takeup difficulties on commercial projectors is to use only reels with an inside diameter not less than about 4-7/8 in.; this dimension is maintained on all

American War Standard reels of 800 ft. and larger. Bell and Howell and current Eastman Kodak reels can be relied upon to meet the essential requirements of the American War Standard Z52.33–1945 (under revision).

In at least one model, Bell and Howell (Fig. 109) has attempted to circumvent takeup trouble by having an intermediate fabric belt drive between the main spring belt and the takeup spindle. As the amount of film on the takeup reel increases, the increase in weight of the film causes an increase in driving torque because of the increase in tension of the intermediate fabric belt. This form of takeup has been one of

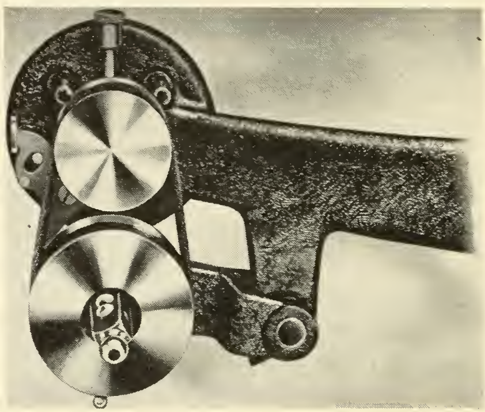


Fig. 109. Takeup arrangement of Utility model projector (Bell and Howell).

the most successful of the simple mechanical designs. A good takeup is one that does not subject a film to a tension greater than 5 ounces nor less than 2 ounces at any time when taking up with any reel from the 400-ft. size to the 2000-ft. size. Incidentally, a tension not greater than 3 ounces is desirable for the feed reel of a projector.

Sound Translation

Sound and Its Reproduction. The sound translating system of a 16-mm sound motion picture projector is located between the bottom of the picture gate and hold-back sprocket that feeds the film to the takeup reel. For practical purposes we may consider the translating system to be divided functionally into two main portions: (*1*) the sound transport system; and (*2*) the optical system and its associated amplifier and loudspeaker. A photoelectric cell located at the input of the amplifier con-

verts the light modulation produced by the movements of the film past the light beam into electrical currents. The associated amplifier amplifies the currents to a level suited to the loudspeaker which, in turn, radiates sound directly to the ears of the audience viewing the film.

Sound Transport. Sound transport systems vary widely in design and in performance. Theoretically, the objective of the design is to transport the film past the sound light beam in a fixed plane with constant velocity. Practically, however, all transport systems deviate from this ideal, having spurious speed variations introduced by mechanical and other irregularities and eccentricities that modulate the theoretically constant film velocity. To some degree, all systems have an in-and-out-of-focus effect that arises from the shift of the film from the theoretical fixed plane. In the former case, the speed modulation causes a like modulation of the signal derived from the film. This spurious signal modulation is called flutter. In the latter case, the in-and-out-of-focus effect that arises from the shifting of the actual plane that the film takes as it moves past the sound-scanning beam produces the equivalent of a flutter modulation of the effective width of the scanning beam slit. This latter effect is quite pronounced in several makes of 16-mm sound projectors, but there has been no attempt made so far to measure it separately in order to determine its magnitude, or to set limits for acceptable performance.

Flutter in Transport Systems. The human ear is quite sensitive to frequency modulation of a sine-wave, 3000-cps tone. The sensitivity depends not only upon the amplitude of the variation, but also upon its frequency. Since 3000 cps is a frequency to which the human ear is particularly sensitive to both amplitude and pitch variations, it was chosen as the frequency for flutter testing with test films. The film is recorded at constant amplitude on a machine that has but a small fraction of the flutter to be expected in the best machine to be tested with the film. The American Standard 3000-cycle, Flutter Test Film Z22.43, obtainable from the Society of Motion Picture Engineers, meets this requirement. A flutter bridge for measuring flutter is manufactured by RCA and others; the RCA flutter bridge is widely used. Different flutter-measuring instruments such as the ERP* or the Altec provide different readings for the same phenomenon. The instrument used and the method of test should always be specified when the results of flutter tests are reported.

* ERP division of Western Electric Company.

Projector designs vary widely in performance with respect to flutter. The practical result is a rather wide range of flutter variation among even the present-day products of different manufacturers. As might be expected, the performance of the very best will leave something to be desired when compared with the best current commercial 35-mm theater equipment. The performance of the very best is usually satisfying on most recorded music and on all speech for the average listener, although it may fall short for a critical listener such as a trained violinist who may be listening to familiar instrumental recordings. The SMPE test film previously mentioned is guaranteed to have less than 0.1%

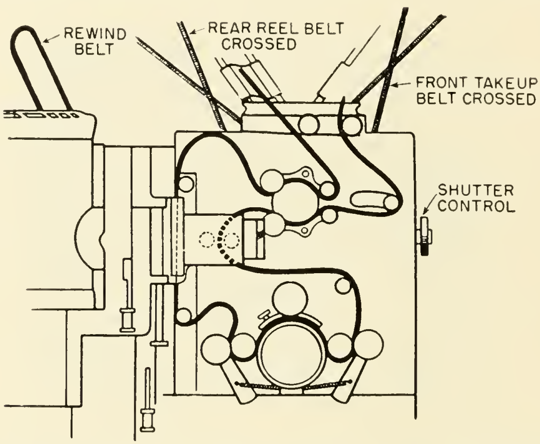


Fig. 110. Film path of old design machine with excessive flutter.

flutter when new. Some of the very best 16-mm machines may show as little as 0.2% flutter when new; however, the flutter in all machines is not equally disturbing at all frequencies. Good performance will show less than 0.25% flutter at rates above 25 cps, 0.15% between 25 cps and 1 cps. An increase in flutter at rates lower than 1 cps is not considered objectionable if it is inversely proportional to the square root of the frequency below 1 cps. It is doubtful than any commercial 16-mm projector meets all these requirements; should one do so by chance, it is doubtful that its performance would continue for any appreciable period due to the influence of machine wear upon flutter. The design of most 16-mm machines provides much room for improvement in the choice of materials and in roller and bearing design, together with a tightening of tolerances of the various parts of the film transport system. Such improvements could result in materially improved performance.

Passable 16-mm performance can be considered twice the flutter limits mentioned above. Although most machines now in use will not come within this limit, many new machines of better grade such as Bell and Howell, Eastman and the DeVry Military Model can meet this requirement when new. Unfortunately, many projectors that are satisfactory when new suffer quick degradation in performance due to such very common causes as failures in the bearings of rollers and idler rollers.

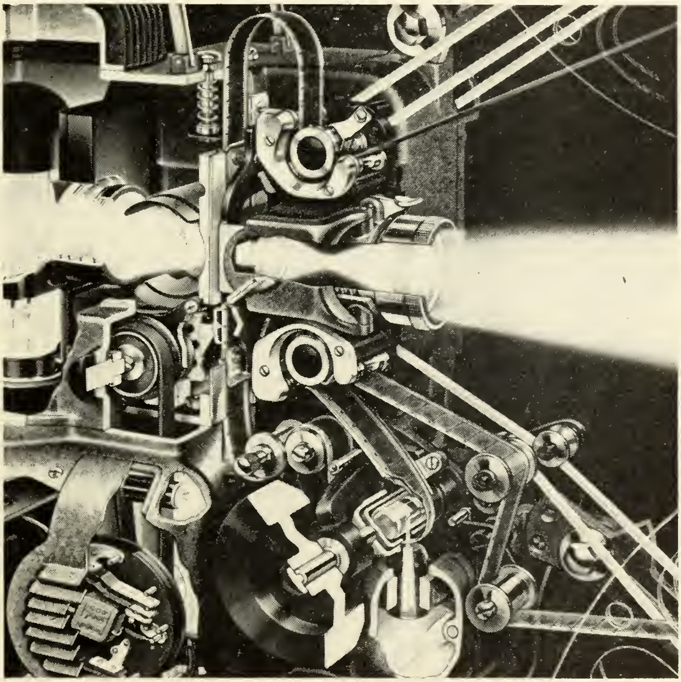


Fig. 111. Assembly of rigidly coupled film-driven drum to well-balanced flywheel (Ampro).

Most film transport systems rely on the holdback sprocket to provide the driving force for the length of film between the intermittent sprocket and the holdback sprocket. One of the poorest transport systems in terms of flutter was that used in the old Victor Animatographs (Fig. 110) more than a decade ago which had a simple chromium-plated fixed gate over which the film was pulled as it passed the light beam from the exciter lamp. When the film was pulled over the fixed gate by the holdback sprocket, the gate friction never seemed to act twice in the same

manner. The "jittery" speed modulation effect became especially serious when the very thin chromium plating of the gate began to wear off. Fortunately, such designs are rarely seen in the better grade machines now manufactured.

A definitely better system uses a film-driven drum that is rigidly coupled to a relatively large flywheel such as the arrangement used in the Ampro (Fig. 111). With this construction there is a relatively large distance—about 32 frames—between the idler roller with its cooperating pressure-pad roller and the overhanging film-driven drum. There is a free-running loop of film that forms between the bottom of the picture gate and the idler roller. In this free loop the major por-

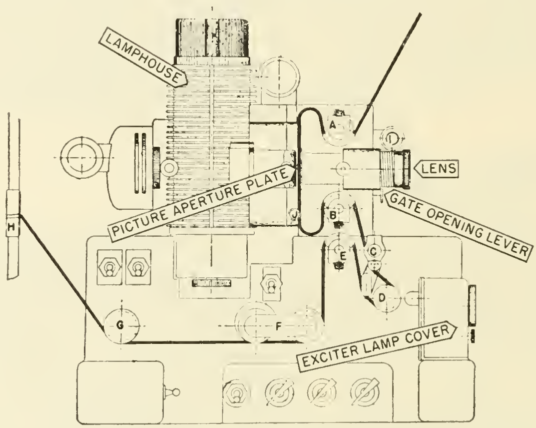


Fig. 112. Threading diagram of Bell and Howell projector in wide use.

tion of the flutter introduced by the intermittent claw is filtered out. Additional filtering occurs between the idler roller and the film-driven overhanging drum where the light beam translates the moving image on the film into light variations. Particularly bad flutter can be produced on this type of machine if the idler roller does not roll or if the pressure-pad roller does not press firmly upon the film as it passes by the idler roller – pad roller combination.

Still further refinements have been made by other manufacturers in various models of their machines. The oil-coupled flywheel first utilized in 35-mm RCA sound heads has been used in slightly different versions and in differing degrees of effectiveness in various models made by Eastman Kodak, Bell and Howell, and RCA. Merely because a particular machine has an oil-coupled flywheel ("fluid flywheel") is no assurance

that its performance is superior to one that does not have it. Just as with other designs, cooperating parts play very important roles in the functioning of the machine and may ruin otherwise good performance. A very common source of trouble is the roller that does not roll. Another is the rubber pad roller with a flat tire. It is not uncommon to find better performance realized in a well-maintained machine with a rigidly coupled flywheel and an oscillatory stabilizer such as the Bell and Howell Utility model (Figs. 112 and 112A) than in a machine with an oil-coupled fly-

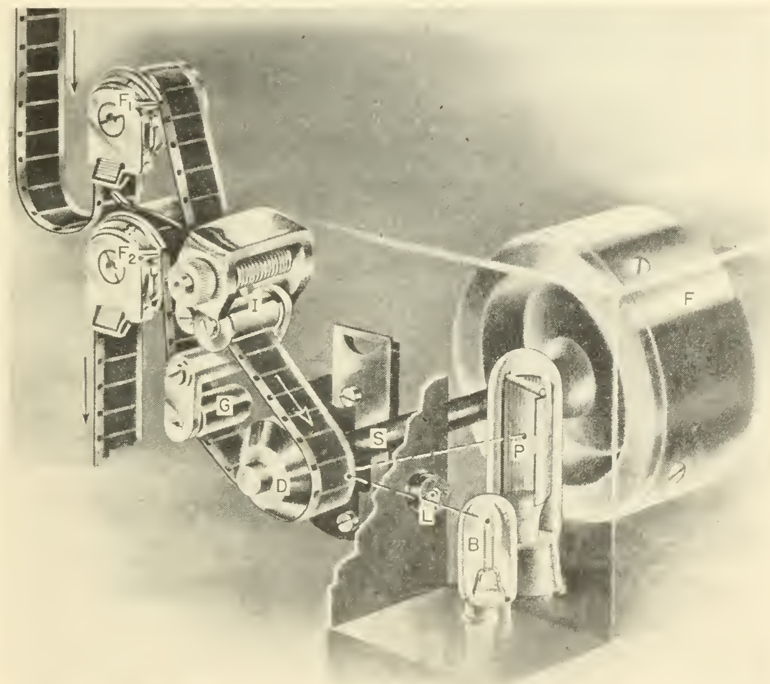


Fig. 112A. Cut-away view of Bell and Howell transport system with oscillatory stabilizer. The flywheel F (at right) is rigidly coupled through shaft S to overhanging film-driven drum D that transports film past scanning light beam. The filament of exciter lamp B is imaged by lens L on sound track of the film that passes around the overhanging drum. After passing through the film, the light beam is reflected by a small mirror (underneath the overhanging film) located a short distance underneath overhanging film. The mirror re-directs light beam to photoelectric cell P connected to input of reproducing amplifier. The film is kept snugly wrapped around the overhanging drum by the spring-loaded oscillatory stabilizer idler I, and the gravity-loaded oscillatory stabilizer G. The film is driven through the sound system loop by the constant speed drive sprockets F_1 and F_2.

wheel using a rubber-tired pressure roller that keeps the film in contact on the overhung drum when the pressure roller tends to stick or when the rubber tire is flat because it was permitted to rest on the drum when the machine was not in use.

Figure 113 shows the RCA Model 400 projector, a post-war design that has many good features.

If a machine has a very good motion with very little flutter, the 3000-cycle tone, when reproduced by the loudspeaker from an American

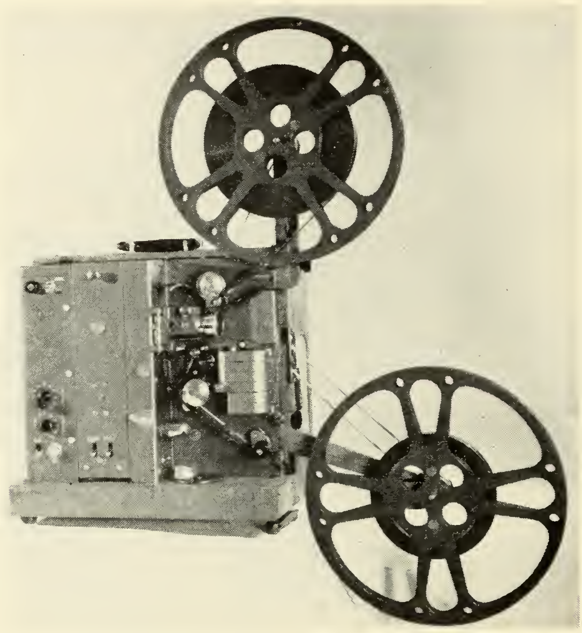


Fig. 113. RCA model 400—a modern 16-mm sound projector.

Standard Z22.43 test film, will sound as if the tone were produced by an audio-frequency oscillator. For even a critical listener the amount of flutter found in the recorded film is so small that switching from an oscillator to reproduction from this film from a grindstone* on an A–B test† will show little if any difference other than a difference in the hiss

* A grindstone is a specially built sound reproducer that has a very small amount of film motion irregularity. The machine used in one case has a sound drum that rotates twice per second with an eccentricity of only 0.0002 in. The flywheel which is rigidly coupled to the drum shaft weighs over 60 lb. and rotates on a single ball bearing.

† An A-B test is a direct-comparison listening test made by electrically switching from one arrangement to the other by snapping a changeover switch.

noise that accompanies the reproduction of the film. Most commercial machines will show definite tone waver; on a better-grade machine the waver should be almost imperceptible to the average listener. It would be good practice to run a short length of about 50 ft. of the 3000-cycle flutter test film as a test every day before a machine is used. This would spare many trained ears from the horror of projectors that wow* and flutter, defects that are all too common and to a considerable degree unnecessary among many machines in everyday use.

Sound Optical System, Amplifier, and Loudspeaker

The Optical System. In most projectors the optical system is quite simple in design and consists essentially of a small helical coiled filament lamp of 6-v., 1-amp. or 4-v., ¾-amp. rating, the filament of which is imaged on the moving film by a simple cylindrical lens.† The light beam emerges from this lens and impinges upon the sound track as a thin line of light perpendicular to the direction of travel of the film.

The light beam is between 0.070 and 0.072 in. long and 0.001 to 0.0005 in. thick; its center is adjusted to scan the film at a distance of 0.058 in. from the unperforated edge of the film. After passing through the film and being modulated by its movement, the light beam is directed to a photoelectric cell where it causes changes in current that are amplified by an amplifier and reproduced by a loudspeaker.

The thickness of the slit image depends upon the optical reduction ratio at which the cylindrical lens is worked. A relatively wide slit will

* Wow represents flutter of dominant rate less than approximately 5 per second.

† This simple system, called the focused filament type, is very efficient in terms of the amount of light flux delivered to the photocell compared with the amount of light flux emitted by the exciter lamp. Because of its simplicity, it does not afford much opportunity for effective color correction; for this reason it is not unusual for the effective slit width to vary markedly from the geometrically calculated slit width. Effective operation with low distortion demands that when variable-area films are scanned, the photocell used shall be very uniform in surface sensitivity. As commercial photocells are not checked accurately for surface sensitivity uniformity, it is possible that occasional cells may show intermodulation distortion as high as 50% if by chance a non-uniformly sensitive cell is chosen. Since the light from a variable density sound track always covers substantially the same portions of the cell surface, this distortion effect does not occur with variable density films. Gross non-uniformity of surface sensitivity of a photoelectric cell may be detected by using a "snake" track test film, ASA Z52.7 that is available through the Society of Motion Picture Engineers. An output meter connected across a dummy load substituted for the loudspeaker will reveal output level variations if a poor cell is in the machine.

pass a relatively large amount of light and provide a relatively large signal for a photocell actuating the amplifier. The wide slit, however, attenuates the high frequencies appreciably with respect to the lower frequencies. To obtain ''balanced'' reproduction without excessive bass tones, both variable and fixed amplifier equalization is provided that is capable of suitably attenuating the bass. In selecting slit-thickness and amplifier characteristics, each manufacturer selects what he considers the best compromise for his particular machine and his concept of ''average'' film quality. In a large number of cases, the basic optical design was accomplished over a decade ago and little significant modification—much less fundamental re-design—has been made despite the fact that raw stock and prints have improved very materially in the interim.

For performance equivalent in response-frequency characteristic to 35-mm performance in a well-maintained neighborhood theater, an effective slit width of 0.5 mil would be required. This value is determined by multiplying the standard 35-mm slit thickness of 1.3 mils by the ratio of the film speeds. Only one manufacturer* (Eastman Kodak) has so far manufactured a commercial sound projector with a slit of this small size. Projector users owe Eastman a debt of thanks for having pioneered in the attempt to accomplish the lens improvement inexpensively in mass production. Most machines were originally designed to provide a slit of 1 mil,† but since chromatic correction was absent, manufacturing tolerances proved wide in practice, and lens inspection in machine assembly was not particularly good, effective widths of 1¼ mils were not unusual. Some lens system modifications proved quite good; an example is Bell and Howell. In their case, improvements in amplifiers and in transport systems made the improvement of the optical system evident in terms of improved sound from the loudspeaker. The lens improvement consisted of a change in the focal length of the cylindrical lens for the purpose of increasing its optical reduction ratio, and/or a change in the size of the small mask at the end of the optical assembly facing the exciter lamp. With all manufacturers, there was a tightening of tolerances, the extent of which varied from manufacturer to manufacturer. Despite these improvements, still further improvement is seriously needed in sound optical and film transport systems; full advantage should also be taken of the recent advances in electronics to reduce the noise and distortion produced in the amplifiers and to widen their frequency range.

* The De Vry and the Bell and Howell Models are not widely available commercially.

† Mil—colloquial term for 0.001 inch.

Most manufacturers today think in terms of a slit of roughly ¾ mil. If the tone control of a machine to be tested is set to provide unequalized reproduction, it is not unusual to find the slit-loss characteristic as measured with a standard frequency film such as ASA-Z22.44 poorer than that expected for a ¾-mil slit. The variation that one is apt to find from the product of one manufacturer to that of another is quite large, and, although the variation from one machine to another of a particular manufacturer is smaller, it is still larger than should be expected with first-grade quality control and inspection in manufacture. One source of difficulty is that there is no standard method of defining slit thickness despite the fact that it is tacitly assumed that slit loss will be expressed in terms of the equivalent theoretical slit. In practice, the slit thickness is always larger by a considerable percentage than the value given by the filament diameter of the lamp multiplied by the lens reduction ratio. The diffusion, the lack of color correction, and numerous other factors vary over such a wide range that any simple geometric estimate of this simple nature is almost meaningless.

Accurate focus and azimuth adjustments are almost as important in sound projectors as in sound recording machines. This is especially true of present optical systems, which are usually little better than marginal in performance. There have been too few improvements in the mechanical design of many machines to make possible more accurate adjustment of azimuth and focus. The combination of marginal optical systems and poor adjustment arrangements in so many machines gives rise to entirely too many cases of submarginal performance in machines in day-to-day use. The situation is especially acute when Kodachrome combination duplicates are projected that have the non-standard emulsion position; the sound track is out of focus by the thickness of the film and in most of the poorer machines there is no provision for altering the focus to correct for the serious losses that are present. Color duplicates are growing daily in commercial importance, and, although steps are being taken in a few laboratories to eliminate non-standard emulsion position color films, it appears that they will still be with us for some time to come.

The Exciter Lamp. The most common form of power supply for the exciter lamp is a super-audible oscillator operating at about 20–25 kcs; its electron tube is fed from the power supply of the amplifier. Alternating current of mains frequency is not used in commercial equipment, since the hum produced would be excessive.

Unfortunately, the small exciter lamps that are used are quite microphonic. The mechanical vibration of the lamp caused by machine vibration results in a significant vibration of the exciter lamp with respect to the optical axis of the optical system—introducing a ringing noise. As the performance demands for 16-mm sound projection are pushed upward, there should be a marked trend toward more rugged lamps with short, thick, rugged filaments; one possibility is the 6-v., 2-amp. lamp that has a more favorable ratio of diameter to coil length. For really satisfactory performance from existing sound projectors, it is usually necessary to select exciter lamps for low microphonic response just as it is necessary to select electron tubes for use in recording preamplifiers. Two or three better-grade lamps are usually found in a box of ten.

Coupling the Photocell to Amplifier. In the design of a sound projector, a design engineer is usually faced with a choice between two undesirable situations; one is to make the electrical connection between the photocell and the amplifier short and direct with the disadvantage of a long optical path, usually involving a mirror, or to make the optical path short and direct and suffer the disadvantage of a long electrical connection. Although the arguments for both sides seem equally valid, the choice from the user's standpoint should be governed by the performance obtained. On this basis the design with the short electrical path and long optical path provides better performance when measured in terms of the signal-to-noise ratio of commercial equipment. Bell and Howell and Eastman machines are typical of the long optical path, while the Ampro is typical of the short optical path.

Most 16-mm sound projector manufacturers make little attempt to minimize the adverse effects of the high coupling impedance and the low signal level in the link circuit between the photocell and the first tube of the amplifier. The adverse effects are, of course, particularly noticeable in the machine with the long electrical path. Although design precautions, such as the use of a cathode follower circuit for the input tube, and inverse feedback applied to the photocell circuit are theoretical possibilities, additional electron tubes would be needed, since most amplifier tubes now in use are already "squeezed" to their operating limits in gain (amplification). Electrical redesign would be expensive, and therefore is not likely to be undertaken without strong consumer or competitive demand for such improvement. As more films and more projectors of better quality become available on the market, the demand will begin to assert itself and to bring improvement with it.

The Amplifier. Most amplifiers in 16-mm sound projectors provide more than 90-db gain, and the electron tubes* used in the earlier amplifier stages preferably should be of the low-noise, non-microphonic types. The best available type is the 1603; the reasons for its superiority in a projector amplifier are the same as in preamplifiers of recording equipment. Most manufacturers, however, do not supply non-microphonic tubes in their machines. In several, a 6J7 is used in the first stage; it may be removed, and replaced with a 1620 without change of electrical connections. In a few others, a 6C6 is used; it may be replaced in similar manner with a 1603. In many machines the choice of the input tube and its circuit represents poor design, particularly when judged by the criterion of noise; either major modification of the design or replacement by a better amplifier is the only solution for improved performance. In all commercial machines, appreciable improvement in noise level may be obtained by replacing ordinary commercial tubes with non-microphonic and other selected types.

In the case of machines using 750-w. projection lamps, most audio amplifiers of recent design provide sufficient undistorted power for ordinary purposes. If measured at a single frequency in midrange (*e.g.*, 1000 cps), the maximum output available is usually in the range between 5 and 10 watts at 5% total harmonic distortion. Unfortunately, the intermodulation distortion in most amplifiers is far too high. Most audio output transformers, for example, follow the undesirable design practices of ordinary home radio sets and are entirely too small for the power they are rated to transmit. Even in the most expensive machines, the output transformer usually weighs less than 1 lb., while an adequately designed transformer should weigh about 5 lbs. if intermodulation distortion is to be kept to a reasonably low level. Because the output transformer is often the only audio transformer in the amplifier, the small increase in weight and in cost would seem to be a very small price to pay for the improvement in performance. The reduction of hum intermodulation products alone will justify the improvement to any critical user of good film and a good loudspeaker.

The design of the amplifiers found in many current machines is inadequate and decidedly out of date. In entirely too many, little or no inverse feedback is used to reduce distortion, since there is no reserve of gain from which feedback might be applied. Although it has been recognized for a number of years in engineering circles that beam power tubes should not be fed to box-enclosed dynamic cone loudspeakers without

* See page 261.

some 10 db or more of feedback around the output tubes, such machines are still being sold in large numbers despite the lack of this simple yet effective design requirement. If sufficient inverse feedback is judiciously used with the customary tetrode amplifier, using output tubes such as the conventional 6V6 in push-pull, or, better, if a triode output push-pull stage such as a 6AS7G driven by a suitable cathode follower or other low-distortion driver is used, the over-all performance of good film with a good loudspeaker would surpass even the optimistic hopes of the average 16-mm film user. It is a sad commentary that many present-day 16-mm audio systems have excessive intermodulation when compared with the 16-mm triode-output amplifiers used over 15 years ago in the very first commercial 16-mm machines.

Most machines have both a volume and a tone control. In some machines, the volume control is an interstage control in the amplifier; in a few others, it is a rheostat in the exciter lamp circuit. A disadvantage of the rheostat type is that the signal-to-noise ratio becomes poor when the lamp current is cut down to reduce volume; however, the exciter lamps last longer. In a few cases the tone control is merely a variable resistor-condenser combination that reduces high frequencies in the manner of similar tone controls in radio sets. In most cases, the tone control is a variety of inverse feedback control that alters the low frequency end of the spectrum when turned in one direction, and the high frequency end when turned in the other direction.

The Loudspeaker.* The almost universal use of the direct-radiator type of loudspeaker—known often as the dynamic cone loudspeaker—is due to the simplicity of its construction and to its low cost. Because of the influence of price-competitive home radio set design, even the loudspeaker supplied today is not as satisfactory from the standpoint of distortion as the heavy loudspeakers of 15 years ago or more. The efficiency of a loudspeaker, like any other form of electric motor, depends upon the flux density in the air gap, the length of the conductor in the gap, and the current through it. To reduce cost in electrodynamic loudspeakers, the amount of copper used in the field structure was reduced from several pounds to a fraction of a pound; when permanent magnets were substituted for electromagnets, there was no attempt to provide the large field flux of the earlier heavy electromagnets. To offset the loss in loudspeaker efficiency due to the reduction in magnetic flux density in the air gap, the power output of the amplifier had to be increased. Unfortunately, high power output was obtained only with

* See pages 300–303.

high amplifier distortion. In addition to this distortion, the relatively great voice coil current of the loudspeaker produces a magnetic voice coil flux that is large in relation to the flux provided by the field. The over-all result is truly excessive distortion when compared with the first commercial 16-mm sound projectors.

Fortunately, loudspeaker design has improved considerably due to the availability of Alnico V since World War II. This material makes possible the same flux density as Alnico III magnets of more than 4 times the

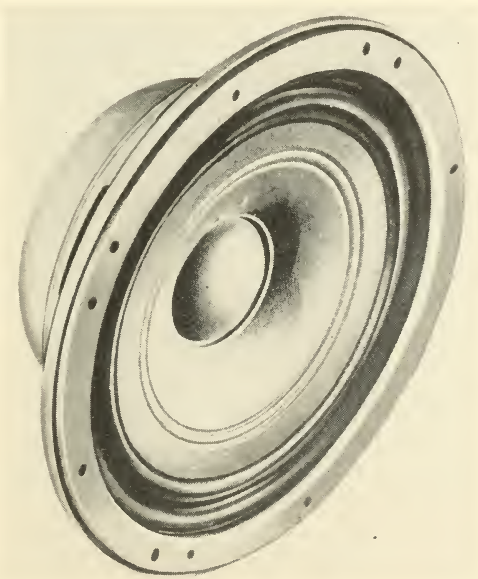


Fig. 114. Western Electric 755A loudspeaker mechanism. One of the finest single-unit loudspeakers manufactured. A significant improvement in performance will usually be obtained with all better grade 16-mm sound projectors if this loudspeaker is substituted for the one presently used. *Power handling capacity:* 8 watts. *Frequency range:* 70–13,000 cps. *Coverage angle:* 70 degrees. *Voice coil impedance:* 4 ohms. *Efficiency:* At 30 ft. on axis, a level of 81.5 db above 10–16 watt per sq. cm. at 8 watts input. This level rating is based on a warble tone covering 500 to 2500 cps. *Over-all diameter:* $8\frac{3}{8}''$. *Depth over-all:* $3\frac{1}{8}''$. *Weight:* 4 lb. 12 oz. *Baffle hole diameter:* 7″. *Mounting holes:* 4 equally spaced on $7\frac{5}{8}''$ circle. *Speaker enclosure recommended:* 2 cubic feet.

weight. The new RMA standard 4.64-oz. magnet, for example, provides the same flux density as the former 20-oz. magnet of Alnico III. A good design of direct-radiator loudspeaker is the Western Electric 755A (Fig. 114), that is rated as 8-w. continuous rating; this loudspeaker weighs

4 3/4 pounds, and functions remarkably well in an enclosure of only 2 cu. ft. Since most of the weight of this loudspeaker is in its Alnico V magnet, it is highly efficient, and is quite free of distortion, including that due to interaction of field flux and excessive flux due to the voice coil. Incidentally, the voice coil impedance of the 755A is 4 ohms, the current RMA standard. Voice coil impedances in 16-mm projectors are often in the same range as in 35-mm equipment, from 10 to 20 ohms—averaging about 16 ohms. To use a Western Electric 755A loudspeaker ordinarily requires a separate transformer to couple between the amplifier and the loudspeaker. Ideally, in a dynamic cone loudspeaker, low frequencies are most efficiently radiated from a large diaphragm (18 in. is often used) with a fairly large and heavy voice coil usually wound with heavy copper wire. High frequencies are most efficiently radiated from a small diaphragm (as small as an inch or two) with a small and light voice coil usually wound with aluminum wire of rectangular cross section to avoid "waste space." The Western Electric 755A loudspeaker represents one of the best compromise designs in a single-diaphragm mechanism for these conflicting design requirements of both low frequency and high frequency radiation in a dynamic cone type mechanism.

Unfortunately, the performance of the box-enclosed, cheap dynamic cone loudspeaker furnished with the average 750-w. projector is very poor compared with the quality of the Western Electric 755A. The magnet is usually small, providing a small field flux. Many amplifiers used to drive such speakers have very little damping;* their internal impedance is high rather than low.

To add still more dissatisfaction, most dynamic cone speakers provide very little high frequency response (response above 3500 cps), and, what little there is, is poorly distributed about the axis of the loudspeaker. Because of its low cost the design is very simple, and a single diaphragm —relatively large—is used with no serious attempt to eliminate the characteristic defect that the radiation angle of the loudspeaker becomes more and more narrow as the frequency of the transmitted tone increases. Typical loudspeaker characteristics of commercial machines are shown at the end of this chapter.

From the use point of view, it is logical to expect that a loudspeaker

* Suitable damping can be provided by using triode output tubes suitably loaded electrically, and by using inverse feedback especially around the driver and the voltage-amplifying portion of the amplifier. Output tetrodes such as the 6V6 and 6L6 may also be used with feedback as previously mentioned. For details see chapter on loudspeakers in *Radiotron Designer's Handbook* by F. Langsford Smith published by RCA.

should cover with sound the area that is served with picture; the "loss in quality" at the boundaries of the viewing space should preferably be no greater in one than in the other. The performance of the loudspeaker is therefore of especial interest at the far corners of the viewing space, at the rear-center of the viewing space, and along the edges of the viewing space quite as much as it is at the perspective center. In 35-mm entertainment theaters it has been found that the only practicable solution to the problem of providing the required performance is the divided-range loudspeaker which consists of two separate mechanisms, a dynamic cone

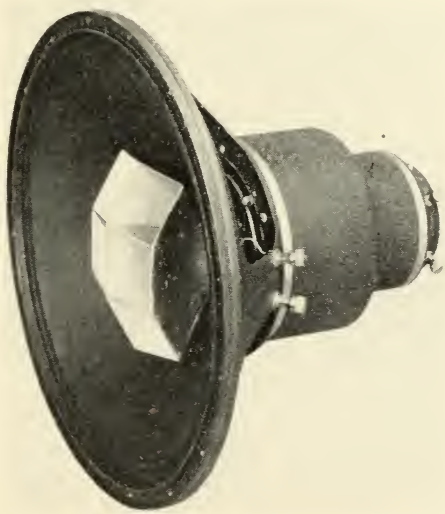


Fig. 114A. Altec-Lansing 604 type loudspeaker mechanism.

loudspeaker for the low frequency range up to the crossover frequency of 400 to 800 cps, and a horn loudspeaker to "aim" the sound suitably for the range above the crossover frequency. As the problem of 16-mm sound projection is functionally the same, the solution is fundamentally the same. Much sacrifice must be made with 16-mm projection because the loudspeakers alone in a theater usually cost more than the complete 16-mm sound projector equipment.

The performance of the divided-range type of theater loudspeaker can be approached to an agreeable degree even in approximately the small space of the customary box-enclosed 16-mm loudspeaker, if the Altec-

Lansing 604 type (Fig. 114A) is used. This unit, when properly placed with respect to the space to be covered with sound, can cover not only the perspective center but also the boundaries. Other loudspeakers with sacrifices in performance of varying kinds may be obtained at lower cost. In comparing these, it would be well to use the Western Electric 755A as a performance reference if the price for the unit in question is between these two.

The horn-type loudspeaker should preferably be used especially for the speech intelligibility frequencies that lie above 1000 cps. This type provides: (*1*) good efficiency (20% is not uncommon compared with 3 or 4% common for ordinary dynamic cones); (*2*) good and reasonably uniform directional radiation (over 60° is easily accomplished at 6000 cps compared with as little as 10° for the conventional dynamic cone); (*3*) good transient response on speech sounds, a result of good damping and uniform impedance characteristics (the horn-type design is almost ideal for the speech range, the single dynamic cone is one of the poorest, especially if it has the large diaphragm and the large-mass voice coil essential to good radiation of low frequencies); (*4*) a much smaller difference in sound pressure at the front row center compared with the last row at the extreme sides. (Sound from the horn-type should be almost as clear and distinct as up front, whereas the sound from the dynamic cone type will probably be low in volume and possibly unintelligible.) The advantages can be readily observed if the loudspeaker of a current model Bell and Howell sound projector is replaced with an Altec-Lansing 604 speaker in its box enclosure, or, should the additional bulk be no disadvantage, replaced by such speakers as the Bell and Howell Orchestricon (made for Bell and Howell by Jensen) or similar divided-range speakers made by Jensen, Stephens, Altec-Lansing, Klipsch, Western Electric, RCA, and others.

Since the recent advent of Alnico V and other improved materials, manufacturers have been vying with one another in the design of loudspeakers that may be satisfactorily applied to 16-mm sound projection. The cost of Alnico V is but a small percentage more per pound than its predecessor Alnico III; as the size and weight of the slug necessary to provide a specified flux is reduced to about one-fourth, a reduction in magnetic leakage has also been possible resulting in still better loudspeaker performance. Despite these improvements, the cost of a really satisfactory loudspeaker for 16-mm sound projection still represents a very appreciable percentage of the cost of the complete machine, and,

although design competition in the near future will drive prices downward and performance upward toward the desired goal, the prospects of obtaining a good loudspeaker for the present manufacturing cost of $3 or $4 still seems remote. It would seem reasonable to believe that the cost of a loudspeaker for 16-mm projection should be higher than that for a home radio set due to the greater importance of its more stringent requirements. The importance of these requirements is not often consciously realized, and the availability of means to correct them seems still less often appreciated. A wide variety of loudspeakers is already available at a variety of prices—from about $30 and upward (less enclosure); any one of the better-grade units will show a significant improvement in performance over the speaker supplied as regular equipment if the amplifier distortion is not excessive.

Picture Projection and the Audience

Reflective projection is most widely used in 16-mm projection, and some essential conditions for satisfactory operation should be mentioned. The widely used sound projector of the 750-w. lamp type (equipped with a 2-in. lens) will be presumed as a reference. The projector is customarily placed near the rear-center of the projection space, the screen is in front. The audience views the picture that is reflected by the screen.

A matte screen (also called diffusive or flat-white) should be used in every instance possible, since it provides the widest angle of satisfactory viewing. A screen is considered dirty if it appears dark in comparison with a clean sheet of writing paper, and should be replaced for it is wasting from one-quarter to as much as one-half of the light thrown upon it by the projector.

An efficient projector can provide about 250 lumens with a 750-w. lamp operated at rated voltage at its terminals; with good condenser system design in the projector, a 1000-w. lamp of the 10 hour (short life) type can provide about 350 lumens with rated voltage at its terminals. The light output of many commercial machines will fall short of these values, and data on lumens output of a particular make and model of a machine should be obtained from its manufacturer. If 225 lumens is taken as representative value, 10 ft.-lamberts* is obtained if the screen is 5 ft. wide. 10 ft.-lamberts is the value of screen brightness ordinarily sought as a reference standard in 35-mm motion picture theater projection; ASA standard Z22.39-1944 calls for not less than 9

* Assuming a very efficient optical system.

nor more than 14. If the 10-hour, 1000-w. lamp is used, and the projector emits the expected increase in light, a screen 5 1/2 ft. wide may be used at approximately the same screen brightness.

Good tonal quality of the picture is impossible if the room in which the audience is situated is not adequately darkened. A general room light of about 1/10 ft.-candle is not harmful; this is the illumination level at which it is difficult but not impossible to read ordinary newspaper type. If the walls of the room are light-colored and the room is small, this general level of illumination may be reached by the light "sprayed about" by the screen itself during projection. Aside from making provisions for excluding light from the room until the general level of illumination is of the order indicated, it is particularly necessary to make sure that no narrow beams of light (such as sunlight) enter the room to produce bright spots on the walls near the screen or strike other objects in the room from which noticeable reflections may be obtained. For audience comfort, the screen should be by far the brightest object in the room. It is also preferable for the screen to be placed at least several feet away from a nearby wall so that the light "sprayed about" by the screen does not reveal nearby wall detail.

The Non-Theatrical Equipment Committee of the Society of Motion Picture Engineers published a report in the Journal of the Society in July 1941 that provides specific and authentic recommendations relating to the use of 16-mm projectors in classrooms. Much of the data presented is applicable to any kind of 16-mm projection and may be used as a guide to equipment selection and use. One very important point discussed is the location of the audience relative to the screen; for convenience, audience location is described in terms of screen widths. In the case of a machine with a 750-w. lamp, the proper screen width is 5 ft. for 10 ft.-lamberts screen brightness.

(*1*) The nearest row of seats shall be no closer than 2 *w* from the screen; a preferred minimum distance is 2.5 *w*. (In terms of the 5-ft. screen, the first row of seats should be not less than 10 ft. away, with 12.5 ft. as the preferred minimum.)

(*2*) The farthest row of seats shall be no farther than 6 *w* from the screen; a preferred maximum distance is 5.5 *w*. (In terms of the 5-ft. screen, the last row of seats should be not more than 30ft. away, with 27.5 ft. as the preferred maximum.)

(*3*) No seat shall be farther away from the line between the projector and the screen than its distance from the screen. This is equivalent to an angle of 30° on either side of the projection axis.

Although it is definitely undesirable to do so, many screens are operating considerably below the 10 ft.-lambert brightness level. In a number

of cases the screen chosen is entirely too large for the projector. In other cases, improvement can be made by making certain that the terminal voltage of the lamp is in strict accordance with the lamp voltage rating. Projection lamps can be obtained in rated voltages from 105 to 130 in 5-v. steps; it is very desirable that the correct lamp be used in all projection, especially in the projection of color film. Should the screen brightness level drop below 6 ft.-lamberts, the cause should be determined and the condition corrected.

The recommended value of 10 ft.-lamberts should not be considered inflexible. Some films may warrant a somewhat higher value because the prints are dense, while others may warrant a somewhat lower value because the prints are light. Many prints are made light intentionally to attempt to compensate in some degree for the poor screen brightness of the projector; such prints are poor in pictorial quality in that much of the shadow detail is lost. If some degree of deviation is unavoidable, it is preferable that it shall be in the direction of greater rather than lesser screen brightness.

Sound Projection and the Audience

The selection of a loudspeaker that is best suited to 16-mm sound projection at a reasonable price is not a very simple matter. Unfortunately, too, the problem has been underestimated by projector manufacturers; the loudspeaker too often appears as an afterthought rather than a performance-integrated part of the machine. In extreme cases it almost appears as if performance is completely subordinated to low price.

Good sound reproduction involves two major characteristics: the volume of the sound, and its clarity and freedom from distortion. With a good film on a good machine, the volume can be controlled by the volume control; the quality or tonal balance by means of the tone control. Both are partly dependent upon the acoustical conditions of the room or projection space. The volume of sound needed for most comfortable and satisfactory reproduction depends upon several factors other than room size. One of the most important is the reverberation characteristics of the room, which are dependent to a considerable degree upon the amount and the kind of sound-absorbing material present.

A room in which the walls, ceiling, and floor are all of hard materials (cement, plaster, or wood) requires relatively little sound energy from the loudspeaker to produce a loud effect. A particular sound being reflected

and re-reflected numerous times loses some of its energy with each reflection and finally becomes inaudible. A prior sound has not ceased before a subsequent sound appears; sound heard under these conditions does not have the pleasing clearness that occurs in the well-furnished living room of a home where there are curtains, rugs, overstuffed furniture, and cushioning materials that absorb sound to a considerable degree. Such sound may be described as "blurred."

A reasonable starting point for sound projection is a room in which it is easy for two persons—one at either end—to converse in an ordinary tone of voice without difficulty when they are not looking directly at one another. (This avoids lip reading.)

If a room is used frequently for projection, it will pay to obtain expert advice on the best manner to treat it acoustically. Manufacturers of sound insulation materials such as Johns-Manville maintain staffs for the purpose of advising prospective users on how to get the best results per dollar invested. Where the expense of permanent treatment is beyond the budget of the user, less permanent treatments can be made. In the simplest cases, the placing of a few temporary panels of sound-absorbing wallboard may suffice for a very material improvement at very low cost.

It would seem obvious that when sound films are projected the audience should be as well served with sound as it is with picture. To accomplish this requires the right kind of loudspeaker placed properly with respect to the audience in the right kind of room. There are two simple rules that will aid sound reproduction materially.

(*1*) There should be no obstruction between the mouth of the loudspeaker and the ears of *each* listener in the audience. This is best accomplished by elevating the loudspeaker above the heads of the audience; in this position there will be least obstruction by the heads of persons in the forward portion of the audience.

A location that is suitable is at the top center of the screen with the loudspeaker mouth pointing at the center of the audience. In 35-mm entertainment theaters, a perforated screen is used with the loudspeaker behind it at approximately ⅔ screen height. Although this is also a good arrangement, it is not often applicable, since perforated screens are rarely used for 16-mm projection because of the light loss of a perforated screen. Another good location is on a stand at the side of the screen with the center of the horn mouth located at about ⅔ screen height and "pointed" at the center of the audience. In placing the loudspeaker, it should be remembered that when a loudspeaker is not along a line of sight, the listener cannot hear it properly.

(*2*) In the acoustical arrangement of a room, parallel hard surfaces should be avoided by coating one surface of each pair with some kind of absorbent material.

In a room with an audience, it is important to cover that part of the ceiling under which no one sits rather than the part under which the audience is located. Likewise,

in arranging drapes and hangings on the walls, it is not necessary to cover a wall area directly opposite drapes used over windows. In general, parallel surfaces are best controlled by covering only one of the pair of surfaces. In the case of parallel side walls, for example, one wall might alternate with a standard width of wallboard running from floor to ceiling, and no covering for the same width. The opposite wall would likewise alternate except that a covered portion of the first wall would be directly opposite an uncovered portion of the second wall, and vice versa. The rear wall should be almost completely covered if possible.

It would seem apparent that the best control of sound quality is achieved when the sound heard by each listener is that from the loudspeaker alone, unaffected by any blurring caused by the multiple reflections from the highly sound-reflective walls of a reverberant room. Although this theoretical ideal does not obtain in practice, it is possible to select the loudspeaker type so that sound radiated by the loudspeaker is directed only to the audience and not "sprayed" all over the walls, ceiling, and other surfaces where it "bounces," arriving at the listener's ears appreciably later than the sound that issued directly from the mouth of the loudspeaker. To accomplish the desired objective in the most satisfactory manner calls for a horn-type loudspeaker. One several feet long is preferable to the very short horns used in such loudspeakers such as the Altec-Lansing 604. An excellent horn is the Jensen K4-244, but, unfortunately, like all good horns of this kind it is unwieldly in comparison with the relatively small box-enclosed dynamic cone loudspeaker customarily furnished as part of a sound projector.

If the sound radiation of a loudspeaker is non-directional, as is the case with a dynamic cone loudspeaker operating at low frequency, it may be thought of as being located at the center of a sphere of radiation into which sound energy is being transmitted. Remembering that the location of the loudspeaker is also the location of the screen, it is apparent that most of the sound energy is not directed to the audience at all but is radiated to the walls, ceiling, floor, etc., where it is either absorbed and wasted, or partially reflected to the listeners' ears where it "blurs" the direct sound that was heard a moment earlier. A rough calculation will show the high order of magnitude of this waste of energy; it is merely necessary to take the ratio of the volume into which sound is radiated and compare it with the volume in which sound is desired. The former is represented by a sphere of radius equal to the distance from the loudspeaker to the farthest listener in the room, the latter is represented by that sector of the sphere within which the ears of the audience are located. For a loudspeaker mounted at the top center of the screen, the solid

angle to be covered with sound is bounded in the horizontal plane by lines 30° on either side of the audience center along the central axis of the horn, and in the vertical plane by a line from the loudspeakers to the ears of those in the front row of seats as one limit and to the ears of those in the rear row as the other limit with the horn axis located along the center. In terms of angles, this is about 60° in the horizontal plane and 30° in the vertical plane. The solid angle to be covered with sound is but 1/72 of that radiated by a non-directional loudspeaker. If the energy

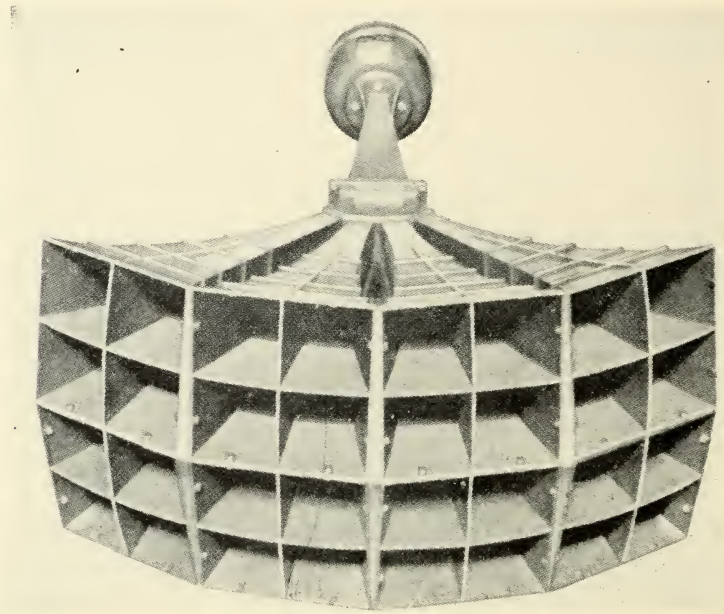


Fig. 115. Jensen multicellular horn with loudspeaker mechanism.

radiated into all portions of sphere is the same (as may be assumed for a non-directional speaker), 71/72 of the sound energy is wasted and only 1/72 is utilized directly by the audience. It seems very strange indeed to build amplifiers of more than 15-w. undistorted electrical output for the doubtful luxury of wasting most of the sound radiated from a directionally faulty and inefficient box-enclosed dynamic cone loudspeaker that distorts badly in order to provide but a small percentage of its radiated sound to the audience. The box-enclosed dynamic cone loudspeaker is not entirely non-directional; it is substantially so at the low frequencies in the frequency range where most of the energy of "average" sound is located.

In reverberant auditoria such as schoolrooms, and the assembly halls, of schools or churches, reverberation is a serious deterrent to the intelligibility of recorded speech sounds. As it is usually more serious at low frequencies than at the higher frequencies, attenuation of the low frequencies is desirable. A really good, but expensive, permanent arrangement is to mount a Jensen K4-244 horn (Fig. 115) at the top center of the screen, "pointing" it downward toward the center of the audience. For most films, no low frequency loudspeaker unit is needed; a Jensen Type F high-pass filter should be connected to the Jensen XP-191 loudspeaker unit (or equivalent) to prevent mechanical overload and consequent damage. The high-pass filter is designed for cutoff at 220 cps. This cutoff is quite satisfactory for most films in most reproducing spaces. The recommended horn is designed for 90° horizontal and 45° vertical coverage; these angles represent sufficient overlapping for the largest audience that can be suitably served with picture from a conventional 16-mm projector. The use of such a loudspeaker will result in several other benefits simultaneously; these are:

(*1*) Superior transient response—better than any other type.

(*2*) Superior uniformity of horn impedance, resulting in better performance from the amplifier due to the excellent loudspeaker damping.

(*3*) Superior efficiency—several times as high as that of the cheap box-enclosed dynamic cone.

(*4*) Excellent horn directivity with minimum variation in intensity level at any useful frequency for different distances from the horn. The man in the back row of seats hears almost as well as the man in the front row; this is quite different from the customary situation in which the man in the front row is "blasted out of his seat," while the man in the back row can hear and understand very little.

(*5*) Excellent high-frequency directional uniformity—no serious discrimination in high frequencies at the boundaries of the audience area where sound from the box enclosed dynamic cone speaker is often almost unintelligible.

(*6*) Excellent fidelity—negligible distortion compared with that of the conventional box-enclosed speaker.

To arrange a suitable mounting for this loudspeaker in the recommended position, with the loudspeaker mouth slightly forward of the plane of the screen, is not a simple matter as it is almost 4 ft. long and has a mouth almost 3 ft. across. The effort, however, will be well repaid in the improvement of the reception.

Good picture projection and good sound projection can be obtained consistently from good film with good equipment. In sound projection, as in picture projection, meticulous attention to detail is capable of producing eminently satisfactory results where marginal or inferior results

were obtained before. Manufacturers would do well to consider seriously the loudspeaker and its mounting relation to the screen and to the audience. For conventional reflection projection the mounting of a suitable horn-type loudspeaker at the top center of the screen would go a long way toward eliminating the unnecessarily deficient sound performance with which much 16-mm sound projection is afflicted.

Practical Projector Performance

A good sound projector should provide a very steady, sharply focused picture that is evenly illuminated, together with clear, steady, unwavering, undistorted, naturally reproduced sound. It is reasonable to expect this performance not only at the beginning of the first reel projected with the machine, but also throughout each and every reel to be projected. Ordinarily, if a machine provides such performance when new, its performance does not deteriorate suddenly. An effect common to all machines is that the picture focus adjustment changes as the machine heats up, making slight focus readjustment necessary during projection if the machine is used for the projection of several consecutive reels. In most machines this effect, although noticeable, is small.

A good projector should be expected to project film with a minimum of film damage and wear and tear. Library-circulated prints are expected to provide from 50 showings upward before they are discarded; each user of a machine is morally bound to make certain that his machine does not mutilate the film; the 50th user has as much right to a satisfactory showing as the first user. Some well-known machines are "very hard on film," while others are "easy on film." If a loop of film is made up that will run continuously in a projector, that loop should run through the machine at least 750 times without evidence of scratching or damage; it should show no injury to sprocket holes, to the picture area, or to the sound track area. Better grade machines such as the Bell and Howell* can ordinarily run such a loop 3000 times; in a series of tests at the Bureau of Standards just before World War II, one machine proved capable of running such a loop 5200 times.

In the Bureau of Standards tests, a well-known machine with some of the very best features, failed because it proved destructive to film. The maximum life of a test loop obtained with this machine was 700 times, a minimum of about 50 times, and an average life of about 100 times. Such

* The new Bell and Howell Military Model machine, now in development, bids fair to exceed this enviable record and to provide exceptional picture steadiness.

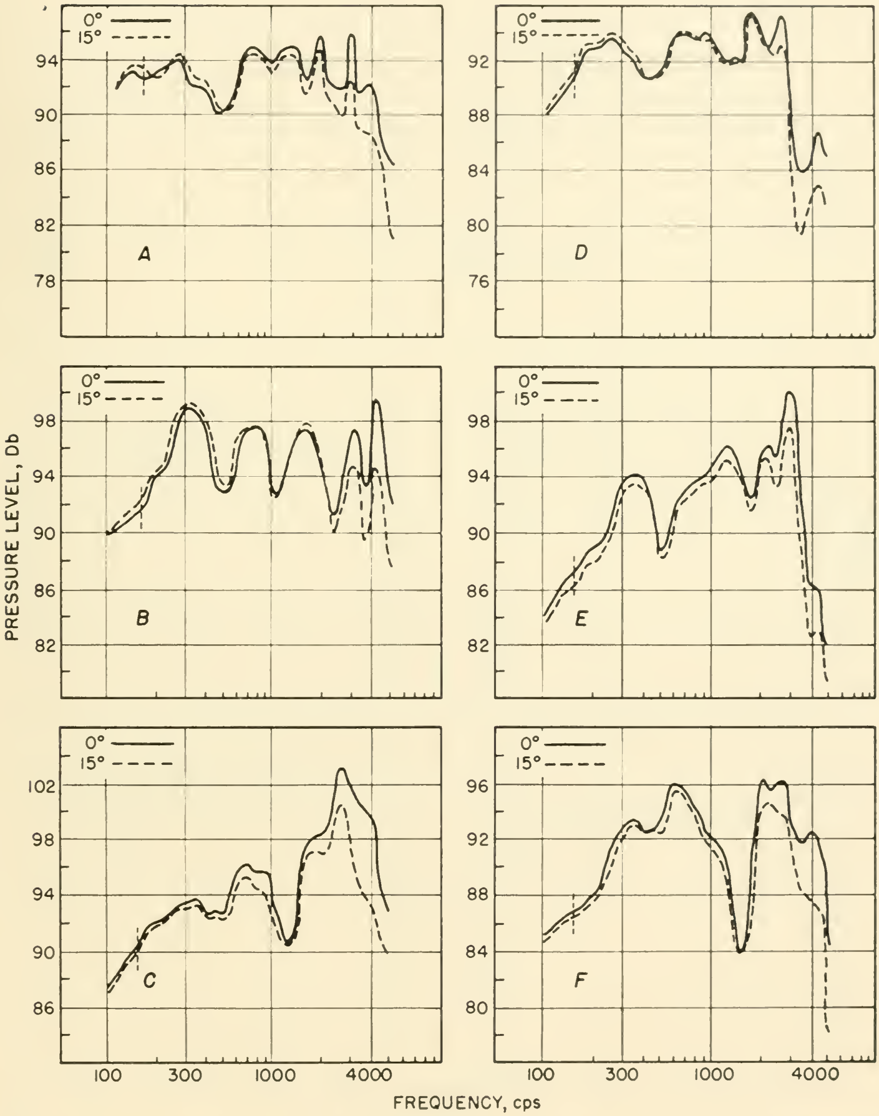


Fig. 116. Over-all response-frequency characteristics of sound reproducing systems of commercial projectors *A* to *F* inclusive. Pressure-level measurements were made with the test microphone placed 5 ft. in front of the front grille of the loudspeaker.

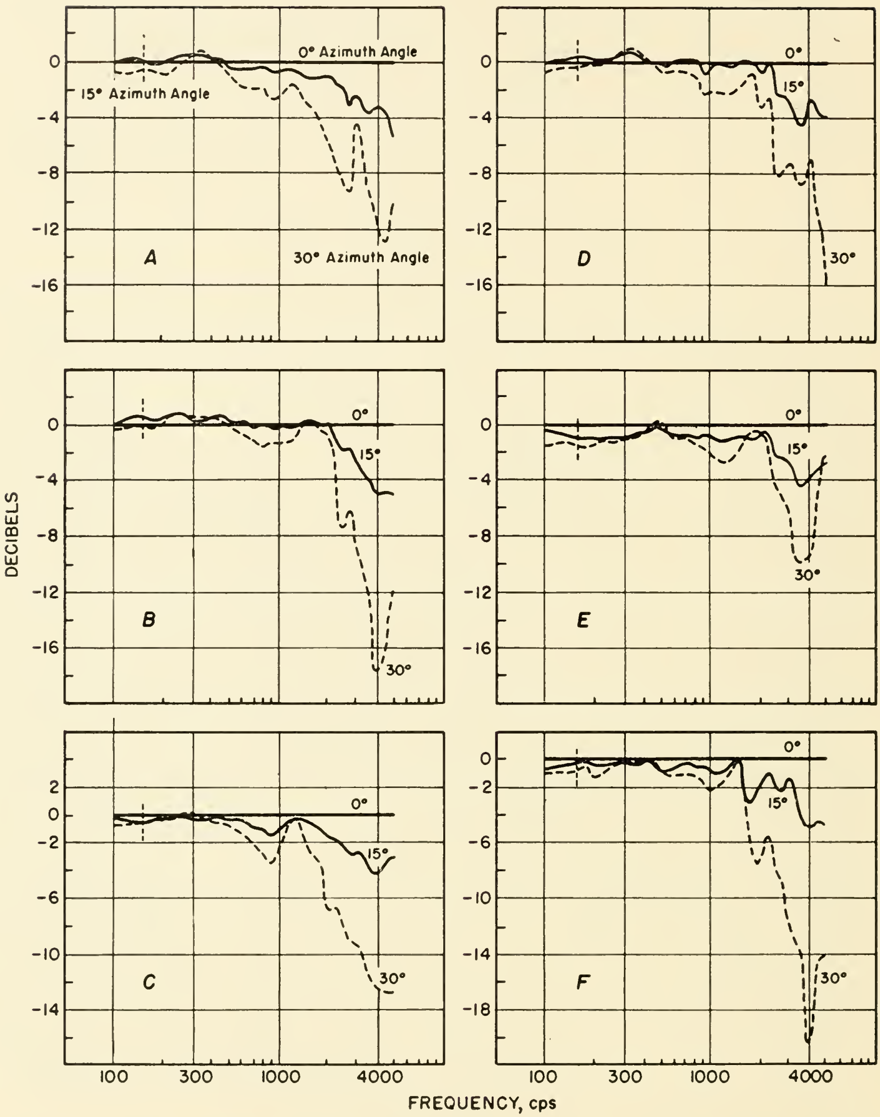


Fig. 116A. Comparison of directional characteristic at 15° and 30° azimuth angle with 0° azimuth angle as reference for loudspeakers of commercial projectors *A* to *F*, inclusive.

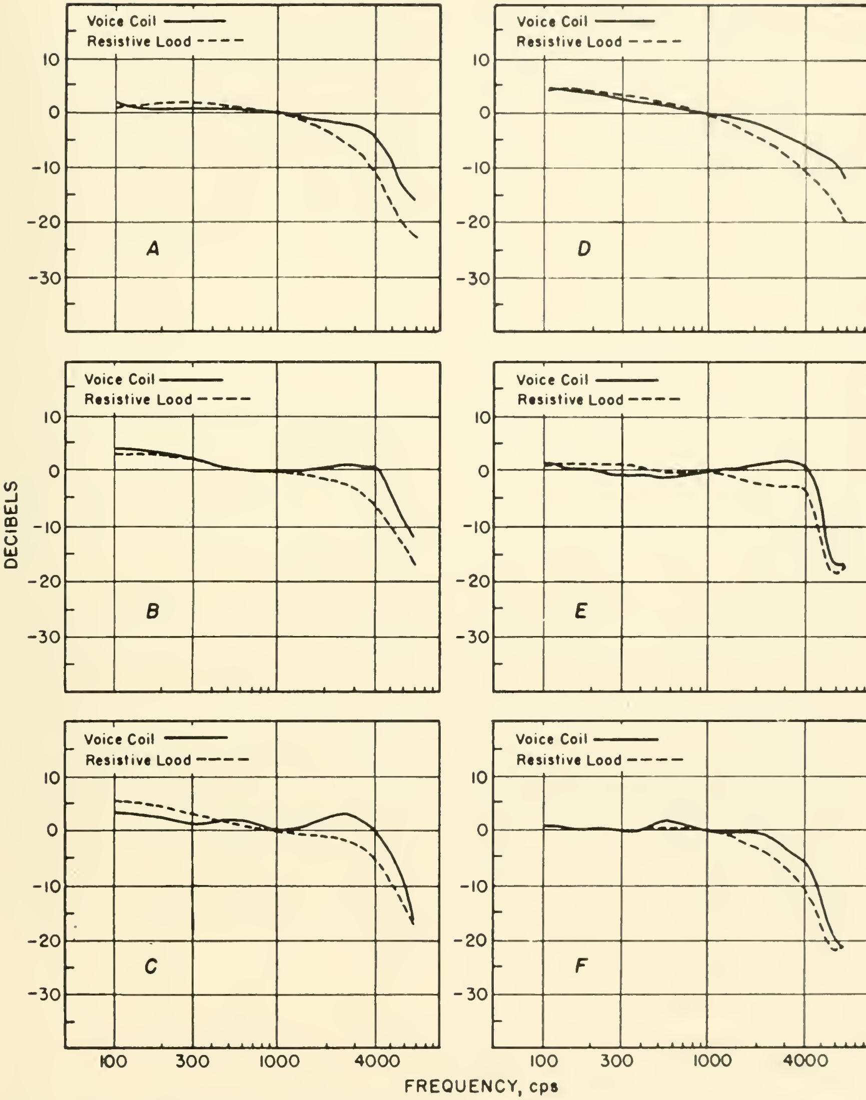


Fig. 116B. Response-frequency characteristics of amplifiers of commercial sound projectors, including the scanning beam for machines *A* to *F*, inclusive. A warble film was run in the projector; the output of the amplifier was measured both across a dummy load resistor, and across the voice coil of the loudspeaker. Power output level was 1 watt at 1000 cps.

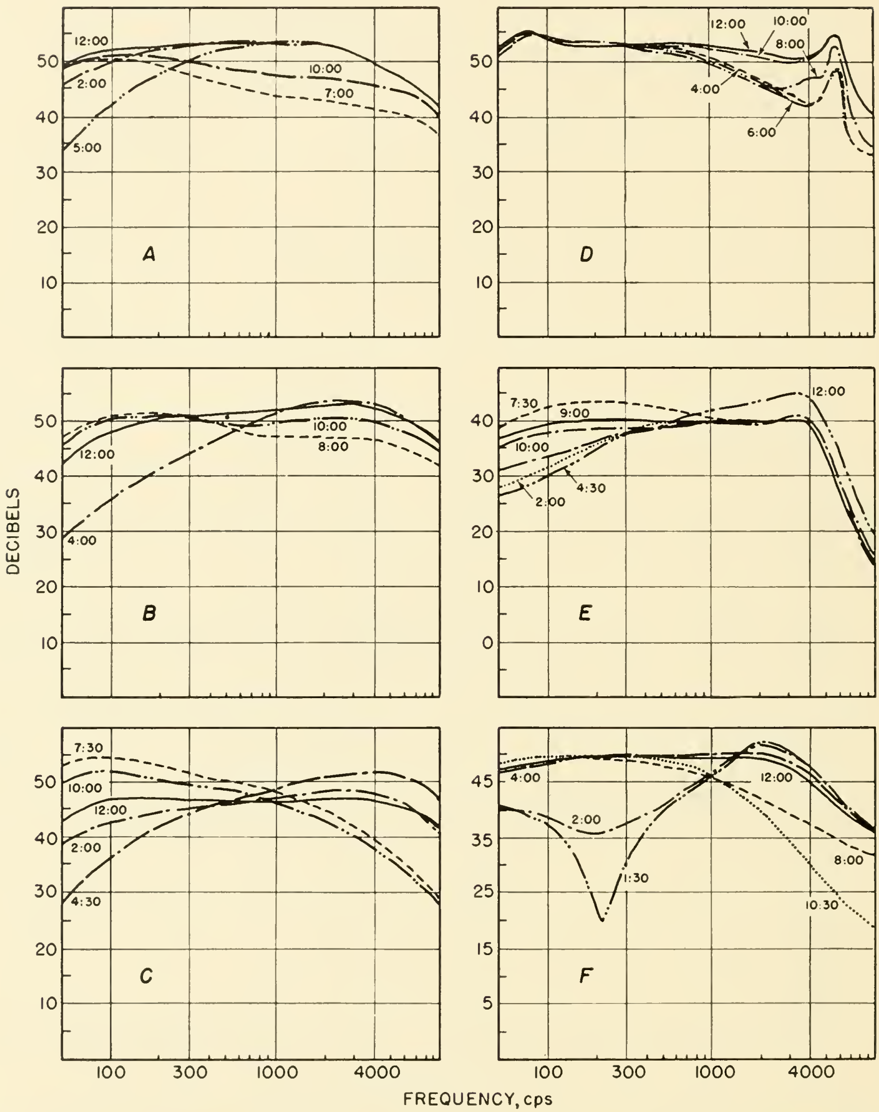


Fig. 116C. Response-frequency characteristics of amplifiers of commercial sound projectors *A* to *F*, inclusive, for various tone control settings.

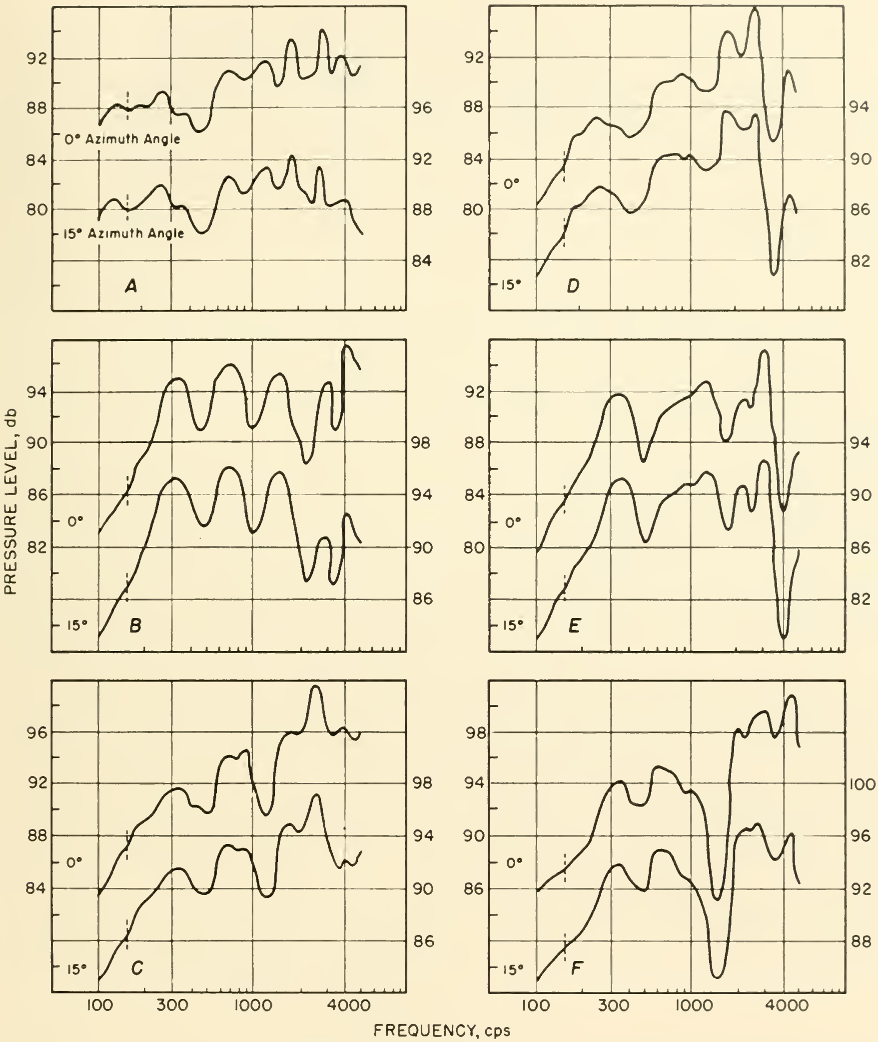


Fig. 116D. Response-frequency characteristics of loudspeakers of commercial sound projectors A to F, inclusive, at 0° and 15° azimuth. Approximately 1 watt was fed into the loudspeaker under test, from a constant voltage source.

TABLE XXVIII

Audio Performance Data of Projectors A to F Inclusive[a]

Projector	Watts rated output	Watts measured output[b]	Signal-to-noise ratio[c]
A	25	19.4	45.7
B	15	13.2	29.7
C	12	11.2	45.6
D	10	—[d]	38.7
E	10	9.6	46.2
F	10	11.8	19.7

[a] Data taken from Tables 4 and 5 of Circular C 439 (pages 25 and 37).

[b] At 5% RMS total harmonic distortion of the test sine wave oscillator signal.

[c] This value is for flat response measured without a neutral density filter.

[d] The total harmonic distortion of this machine exceeded 6.4 percent at all power-output levels.

destructiveness is very serious despite the machine's technical excellence otherwise. The test is a simple one, yet despite its simplicity it is of primary importance. Unfortunately, manufacturers do not usually provide data concerning this essential feature of their machines, and the buyer must find out for himself. Users and prospective users of 16-mm sound

TABLE XXIX

Flutter Performance of Projectors A to F Inclusive

Projector	Amplitude modulation (measured on 2% scale)	Percentage of flutter: Lower limit	Percentage of flutter: Upper limit	Percentage of flutter: Average	Frequency of flutter and aural observation
A	1.55–1.65	0.4	1.0	0.6	Noticeable flutter by aural observation.. Rather violent fluctuations of various periods on occasion.
B	1.55–1.65	0.3	1.2	0.45	Noticeable flutter by aural observation.. Violent fluctuations of various periods on occasion.
C	1.55–1.65	0.25	0.45	0.33	Long period fluctuations of approximately one second.
D	1.55–1.65	0.7	1.4	0.85	Noticeable flutter of various periods by aural observation.
E	1.55–1.65	0.4	1.2	0.7	Noticeable flutter by aural observation..
F	1.56–1.62	0.45	0.62	0.53	Noticeable flutter by aural observation..

projectors will find it worthwhile to familiarize themselves with the features of 16-mm sound projectors as described in detail in the Bureau of Standards Circulars C-437 and C-439. Although the data is now quite old, there have been few truly significant improvements beyond the published information; certain of the better grade machines have improved slightly, most of the others have not.

Figures 116, 116A, 116B, 116C, and 116D describe the audio performance of 6 commercial 16-mm sound projectors tested by the National Bureau of Standards; these data are reported in Circular C439 previously referred to. Table XXVIII describes the output performance of the same six machines with regard to power and to signal-to-noise ratio. Table XXIX describes the flutter performance of the same six machines. It is data such as appear in the foregoing figures and tables that describe the performance of machines for a user; it is regrettable that such data is not published or made otherwise readily available to prospective purchasers of sound projectors. The Committee on Scientific Aids To Learning of the National Research Council is to be warmly congratulated for its planning of this most-needed measurement activity, and the National Bureau of Standards is also to be congratulated for carrying it out with its characteristic methodical precision and efficiency.

Armed with a little knowledge of the design and performance characteristics and requirements of 16-mm projection and projectors, there is little reason why a user should not find current 16-mm equipment eminently satisfactory for projecting good quality current 16-mm films. Test films that may be required for comparative testing of machines or for a routine check of the performance of machines already in service are available through the Society of Motion Picture Engineers. For the serious user, such films are imperative in preventive maintenance; small degredations in projector and in film performance can be detected before a breakdown or serious defect in performance occurs.

Selected Bibliography

''Non-theatrical Equipment Report—Recommendations for Educational 16-Mm Projection,'' *JSMPE, 37,* 22 (July 1941).

Stephens, R. E., ''Optical and Mechanical Characteristics of 16-Millimeter Motion Picture Projectors,'' Natl. Bureau of Standards Circular C437, Washington, 1942.

Snyder, W. F., ''Acoustic Performance of 16-Millimeter Sound Motion Picture Projectors,'' Natl. Bureau of Standards Circular C439, Washington, 1942.

Olson, H. F., ''Extending the Range of Acoustic Reproducers,'' *Proc. Radio Club of Am. 18,* 1 (Jan. 1941).

Jensen Technical Monographs Nos. 1 to 5, incl., Jensen Radio Manufacturing Co., Chicago, 1945.

Hilliard, J. K., ''Theater Loudspeaker Design, Performance, and Measurement,'' *JSMPE, 52,* 629 (June 1949).

Veneklasen, P. S., ''Physical Measurements of Loudspeaker Performance,'' *JSMPE, 52,* 641 (June 1949).

Angevine and Anderson, ''Facts about Loudspeakers'' (a series), Audio Eng., New York, 1948.

Hilliard, J. K., ''Portable and Semiportable Loudspeaker Systems for Reproducing 16-Mm Sound on Film,'' *JSMPE, 49,* 431 (Nov. 1947).

For further bibliographic material the reader should refer to the following indexes to the *Journal of the Society of Motion Picture Engineers.*

July 1916–June 1930

January 1930–December 1935

''Committee Reports—Projection Practice,'' page 16.
Projection Screen Brightness,'' page 17.
Projection Screens,'' page 17.
Projection Theory,'' page 18.
''Electron Tubes,'' page 24.
''Eye-strain,'' page 25.
''Illumination in Projection,'' page 33.
''Incandescent Lamps,'' page 34.
''Lamps,'' page 37.
''Loud Speakers,'' page 39.
''Motor Generators,'' page 41.
''Naval Projection Equipment,'' page 42.
''Non-theatrical,'' page 42.
''Optical Intermittents,'' page 44.
''Optics,'' page 44.
''Photoelectric Cells,'' page 46.
''Portable Equipment,'' page 47.
''Power Supply, for Reproducing Equipment,'' page 47.
''Projection, General Information,'' page 51.
''Projectors, Continuous,'' page 53.
Intermittent,'' page 53.
Portable,'' page 53.
Special Type,'' page 53.
''Rectifiers,'' page 54.
''Screens,'' page 55.
''Servicing Motion Picture Equipment,'' page 57.
''Sixteen-Millimeter Equipment,'' page 57.
''Sound Installations in Theaters,'' page 58.
''Sound Reproduction, General Information,'' page 62.
''Test-Films,'' page 67.
''Theater Characteristics,'' page 67.
''Theater Design,'' page 68.
''Theater Equipment,'' page 68.
''Theater Noises,'' page 68.
''Theater Operation,'' page 68.
''Vision,'' page 69.
''Visual Fatigue,'' page 70.

1936-1945

''Amplifiers,'' page 73.
''Arcs,'' page 74.
''Loudspeakers,'' page 106.
''Optics,'' page 111.
''Projection,'' page 122.
''Projectors,'' page 126.

''Rectifiers,'' page 127.
''Research Council,'' page 127.
''SMPE Activities, Projection Practice Reports,'' page 129.
Theater Engineering Reports,'' page 131.
Non-theatrical Equipment Reports,'' page 129.
''Screens,'' page 133.
''Screen Brightness,'' page 142.
''Sound Reproduction,'' page 143.
''Sprockets,'' page 148.
''Theater,'' page 152.
''Vision,'' page 154.
''War Committee on Photography, Z52,'' page 155.

CHAPTER XIV

Duplication of Tri-pack Color Films

Years ago when color in motion pictures was just a matter of scientific speculation, Thomas A. Edison expressed the thought that the combination of color and sound in motion pictures would represent the highest pinnacle in motion picture technological achievement. By Edison's criterion, it would appear that we have already arrived at that millennium.

As in the case of prior arts, the daydreams of the pioneers became the realities of a later day. The embodiment of a daydream usually brings forth new problems that must be solved in turn. We may view this as the secondary stage in the development of an art. And so it is with integral tri-pack color films; they are entering the stage of application and intensive secondary technological improvement.

The idea of multilayer films for color purposes traces back to the earlier stages of the motion picture long before sound became a commercial feature. The dye-coupler concept likewise harks back to an early time; its potentialities were appreciated to a remarkable degree as early as 1907. The names of Homolka, Lewy, and Fischer will be remembered as early pioneers with vision.

It has taken a long time for the processes described by these investigators prior to 1914 to become commercial realities. Just as the photoelectric cell had to wait for the coming of electron tubes and amplifiers before sound films could be commercialized, the integral tripack color films had to wait for suitable dyes and other chemicals. As in other fields of invention, each new discovery added to the total store of knowledge and, in turn, each new discovery was found to have its limitations. It appears that there is no solution that will meet all the requirements of an "ideal" color process; there is no "perfect" film or "perfect" process.

Kodachrome Processing and Duplicating: Some History

Additive processes such as the old Kodacolor process gave way commercially to substractive processes. No filters or other gadgets are needed for either camera or projector when integral tri-pack subtractive color films are used; this was considered a "must" for color film for the

amateur. Kodachrome—introduced in 1935—is the most widely used 16-mm motion picture color film. It was made simple for the user despite the fact that it was complex in manufacture and in processing. When it was first introduced the developing process included approximately 30 stages, each of which required precise control. The process worked well; amateurs and others bought film, exposed it in their cameras, and projected the results in color. Kodachrome is a 3-color subtractive reversal film.

To an operator of a commercial film laboratory, the requirement that a particular piece of film must go through about 30 control stages automatically brought the reaction "I'm glad that it is the manufacturer's problem and not mine." In black-and-white commercial laboratory work we still seem to have considerable difficulty today with but a fraction of that number of control stages.

It was logical to expect the Eastman Kodak Company to simplify such a complex developing process in order to cut operation costs and to reduce the risks of damage during processing. Such simplifications had to be introduced while commercial film was being processed daily; if the customer were to be aware of the difference at all, he should observe it as an improvement. Obviously, something in the process had to be "tied down." It is fair to say that the average user was not aware that changes in the process were constantly being made; yet there were unmistakable signs that Kodachrome was improving. There was close control of emulsion manufacture and of color developing as well as coordination between them. The selling price of the raw film included the developing cost; there was little opportunity on the part of the manufacturer's laboratory to "pass the buck." (No commercial laboratory attempted to color-develop Kodachrome; no such laboratory, regardless of its personnel and equipment, could ever hope to operate at a profit under such strict control requirements especially since the developing cost was already included in the price of the raw film and when the process itself was in a "fluid" state.)

When Kodachrome first made its appearance, it was logical to expect that attempts would be made to duplicate it. In the earliest stages, duplication was little more than placing Type A raw film in a contact printer with the original picture and then snapping the switch. The printed film was hopefully shipped to Rochester; occasionally, a commercially usable developed roll would return. Oftentimes, there was an apologetic letter together with a new roll of raw film.

When commercially usable films started to return from Rochester a

little over a decade ago, a commercial duplicating business was born. Even at that early stage, the advantages of color and sound in 16-mm were appreciated; a survey of certain industrial film users showed that more than 90% of those canvassed wanted color in their 16-mm sound films—and only Kodachrome was able to give it to them. The rapid growth of Kodachrome duplication, therefore, was not entirely unexpected.

Available Types of Kodachrome

Kodachrome for duplicating is sold in a single contrast and color balance: duplicating, for 2900K source temperature, code EK 5265. 16-mm Kodachrome is designed to be used with a specified arrangement of filters for "balancing" purposes and with the lamp operated at the specified temperature of 2900K. Further data on the process will be given later.

The duplication of Kodachrome has grown in volume to the point where each of several laboratories not connected with the film manufacturer is printing several million feet per year. The total handled by all users is a truly large item when we remember that the average cost is approximately 12 cents per foot compared with approximately 2.5 cents per foot black and white.

Ansco is also marketing duplicating film; although the result is quite different from that with Kodachrome, the general methods are quite similar. The competition can be expected to become especially keen when simplified methods for reducing resolving power losses in duplication have been satisfactorily worked out. As a step in that direction, Ansco has anounced a one-strip separation black-and-white film in which the contrast has been adjusted to the requirements of color duplication and each color frame is represented by its three components printed sequentially along the one-strip separation film.

Competitive Positions of Present-Day 16-Mm Color Methods

It would seem worth while at this point to give some thought to the future, as signs point to a still further increase in volume of 16-mm color film. For most purposes, the present Kodachrome product is quite satisfactory. There are several competitive factors, however, that are the imponderables of the future.

First, there is the marketing of AnscoColor Film. At first glance, AnscoColor film would seem to be in the fortunate position of sharing the

future 16-mm market with Kodachrome. The color printing techniques are similar. With good sensitometric control, color development should not encounter any very serious obstacles, although most prospective users will have to begin to learn what quality control and process control really mean if they hope to be commercially successful. This is a very real and serious problem; even the most optimistic of us would hardly dare to say that good control has been widely achieved when we screen prints of 16-mm black-and-white films.

The second imponderable is sound. The sound quality available with present-day Kodachrome does not compare with the quality obtainable under properly controlled conditions with high resolving power films, such as the blue-dyed EK 5372 or the yellow-dyed EK 5365. (The rated resolving power of both is 150 lines per millimeter.) Bruno does not hold much hope for conventional methods of improvement when he states that both AnscoColor Film and Kodachrome exhibit resolving power of the order of 40 lines per millimeter. It would seem that the difference between Bruno's measurements and the Kodak rating of 75 lines per millimeter can be attributed to a difference in measuring technique. It would be desirable to evolve some empirical method for evaluating resolving power. This would avoid apparent discrepancies; to paraphrase Mark Twain, "An argument arises when two people use the same words to describe different things." Possibly two figures might be established: one representing the performance of the picture portion of the film (this could establish agreement upon a single visual method), and the other representing the performance of the sound portion of the film. It would seem that the sound art has already reached the point where some such evaluation method could be used for expressing the performance of a sound record when scanned by the scanning beam of a representative projector. Such evaluations would be useful in comparing the performance of black-and-white with color film; a standard projector will project either.

Görisch and Görlich discussed some of the criteria for a satisfactory sound track on multilayer films and reported upon some of their tests. Their conclusion is significant: that the usual caesium-surface photoelectric cell is well suited to the reproduction of silver-emulsion films, but should be modified with antimony if it is to reproduce dyed films satisfactorily. No doubt much undisclosed progress has already been made in making the cell to fit the film and the film to fit the cell. While the general trends that the characteristics should take seem indicated, the

problem is really a knotty one and will require considerable further thought before it is satisfactorily solved in terms of the high resolving power of 90 lines per millimeter required of projection lenses. It may well turn out that the major part of the 16-mm color film market will be initially awarded to the film manufacturer whose product delivers outstanding sound quality as the color problems for the picture seem less difficult to solve.

The third and very serious imponderable is picture detail. The loss in detail in a very well-made Kodachrome or AnscoColor duplicate is excessive when we think in terms of lenses with resolving power of 90 lines per millimeter used on a projector with 50 amp. on the arc throwing light upon a 15-ft. screen. Low resolving power is inherent in multilayer films, as it is necessary that relatively fast individual emulsions be used for even a slow-speed final product. Bruno reports an immediately available increase from 40 to 55 lines per millimeter if certain sacrifices are made in color rendition. In the making of duplicates, Bruno further reports that the number of filters used in printing will have to be kept to a minimum since there is evidence of considerable loss of resolution (about 10%) for every filter introduced in an imaging optical system.*

The fourth and final imponderable is the competitive position of imbibition printing. (Technicolor is an example.) Where the number of prints in an order runs to 500 or more, imbibition printing should show some very generous profits at present duplicate bulk price. An additional factor in its favor is that the resolving power problem does not loom so large when compared with integral tri-packs. Laboratories that duplicate Kodachrome have experienced 500-print orders, and it is likely that they will fight hard to boost quality as imbibition color printing enters the field as a strong and able competitor.

The foregoing and other marketing factors seem to point to the conclusion that 16-mm color-sound printing will probably become competitive in quality and price at the same time. Because of the importance of production methods and their influence on production costs, some notes upon the present Kodachrome duplicating techniques are indicated.

* The Wratten gelatin filters supplied by the Eastman Kodak Company for color printing are considered ''optically inert'' and do not introduce losses as serious as the more permanent glass filters. They are, however, somewhat unstable when subjected to heat and must be checked periodically when they are used in commercial duplicating. The loss in resolution caused by a particular filter in an imaging system varies quite widely when used in different parts of an optical system. Barring heating and similar deteriorating effects, correction filters are best used over the light source since it is here that they introduce minimum loss in resolution.

Picture Duplication

The general instructions for making 16-mm Kodachrome duplicates are found in a booklet "Instructions for Making 16-mm Kodachrome Duplicates on Kodachrome Duplicating Film Code 5265," Issue No. 8, March 30, 1944. This should be in the hands of all those engaged in the business of making Kodachrome duplicates. It is issued by the Motion Picture Film Department of the Eastman Kodak Co; minor revisions are made from time to time.

The basic method is simple. The lamp in the printer is first set and maintained at the color temperature of 2900 K. The intensity is then reduced to the appropriate value by means of neutral density filters or equivalent after the specified printing filters are mounted in place in the light beam.* A test original is then printed; production prints are made after the minor corrections indicated by the test are made. All tests should be made upon the same emulsion lot of film that is used for production printing. Slightly different "balances" are required for different emulsion lots. In other respects, the printing process is comparable to black-and-white printing.

Some Limitation of the Duplicating Process

When certain films are duplicated in the specified manner, the result on the screen may leave something to be desired. There are several possible sources:

(*1*) *An accurate copy of the original may not be desired; the color balance of the original may be quite different from that desired in the duplicate.* It often happens that colors "ideal" for Kodachrome are not possible or convenient in the original photographing; photomicrography, where bacteria dyes and stains are involved, is a typical example.

(*2*) *The exposure of the original may be quite different from that desired in the duplicate.* One example would be the exposure required for a short sky shot interposed between two shots of dark woodland; such a sequence might be found in a training film dealing with the landing of airborne troops.

(*3*) *The duplicating process itself has limitations.* Some practical duplicating problems cannot be solved satisfactorily by merely following the printed Kodak instructions; they require an understanding of the pertinent limitations of the process.

* A filter pack includes an infrared limiting filter and an ultraviolet limiting filter; these are intended to limit the exposing radiation to the 400 to 700 mμ range. In practice, the former filter may be a Corning Aklo #3966, the latter a Kodak Wratten #2B. If the printer has a single light beam, it uses subtractive filters as "balancing" filters; these may be a CC-30C (cyan filter of 0.3 peak density) and a CC-10M (magenta filter of 0.1 peak density). Other color compensating filters available are yellow (minus blue) and red, blue, and green; all are available in peak density steps of 0.05.

Theoretical Elements of the Color Process

As a starting point, we may say that the color spectrum has been arbitrarily (yet with good reason) divided into three major parts. For the purpose of duplicating, a color compensating filter may be considered theoretically to provide attenuation in only one or two desired parts of the spectrum without affecting the remainder. As will be seen on pages 510 and 511 this idealistic state of affairs was not strictly true of the color-compensating filters available around 1949, and although changes and improvements in filter dyes have been made, it is not practical to assume it true for commercial filters today. Table XXX lists the ratings of the present (1953) Kodak Wratten color-compensating filters.

TABLE XXX

Ratings of Kodak Wratten Color-Compensating Filters

Peak density	Yellow (– blue)	Magenta (– green)	Cyan (– red)	Blue	Green	Red
0.05	CC-05Y	CC-05M	CC-05C	CC-05B	CC-05G	CC-05R
0.10	CC-10Y	CC-10M	CC-10C	CC-10B	CC-10G	CC-10R
0.20	CC-20Y	CC-20M	CC-20C	CC-20B	CC-20G	CC-20R
0.30	CC-30Y	CC-30M	CC-30C	CC-30B	CC-30G	CC-30R
0.40	CC-40Y	CC-40M	CC-40C	CC-40B	CC-40G	CC-40R
0.50	CC-50Y	CC-50M	CC-50C	CC-50B	CC-50G	CC-50R

Since 1952 negative-positive color films have become available in addition to color reversal film. Color reversal films have decided advantages in ability to render fine detail; negative-positive films have decided advantages in gamut of color reproduction, especially where copies of a film are required. The quality of both can be improved materially by the use of the new commercial 3-color printers such as DeBrie introduced in 1953; this printer utilizes a single light source and employs a beam splitter to divide the exposing beam at the aperture into the three additive primaries—green, red, and blue. Filters used: #57A and #12—green; #29—red; #47 and 2B—blue. In practice, the Kodak set of filters is adequate in most cases, but there is a small number, particularly those cases in which large-order corrections are to be introduced, in which

the simplified Kodak procedure leaves something to be desired. A study of the process should explain the discrepancies.

Color Standardization. As a starting point, we have a standard called *The Specification and Description of Color* issued as American Standard Z44–1942 by the American Standards Association. Section 2.1 reads: "the spectrophotometer shall be recognized as the basic instrument in the fundamental standardization of color." A convenient instrument that is commercially available is the General Electric Recording Spectrophotometer. This instrument is widely used; it is available in commercial testing laboratories such as Electrical Testing Laboratories in New York. Curves* shown in this chapter were taken on this instrument.

Gage has reviewed color measurement and sets forth some of the terms regularly used to describe the attributes of color. There is a generous list of references at the end of the paper for those who are interested in the many scientific aspects of color.

No discussion of color standardization, however brief, can be considered complete without mention of the ICI Standard Observer and Coordinate System for Colorimetry. Color specifications prepared in accordance with this internationally accepted method can be computed from spectrophotometric data. Unless otherwise specified, standard ICI illuminant *C* (representative of average daylight) is assumed. Results of the computations are expressed in a table of three values for each wavelength in the spectrum. These data are then plotted as a curve for convenience. Owing to the computations required, this method of describing color is limited in its use; for most purposes, curves taken by the recording spectrophotometer are preferred.

The *Munsell Book of Color* must also be mentioned as a catalog or atlas of color that is in wide use. This book is made up of a large number of color samples. The characteristics of many of these have been measured on the recording spectrophotometer and also translated into ICI terms. The colors in this book were used as a standard prior to 1931 at which time the ICI formulated the present system. The Munsell Book is still of real value as a reference not only because of the great variety of colors included, but also because of the uniformity and the permanence of the materials used for them.†

* Furnished through the courtesy of Dr. J. L. Michaelson of General Engineering Laboratory of General Electric at Schenectady.

† The Ridgway color standards (1912) are of considerable interest to naturalists, botanists, and biologists. Unfortunately, many of the reference color chips fade.

The Textile Color Card Association of America has taken the lead in recommending the use of standard names for colors used in the textile industry. The Association has not only selected suitable names for the colors but has also been analyzing each color spectrophotometrically. It is not uncommon for specifications to describe the colors of radio hookup wire insulation and of color coding of the resistance values of resistors used in radio equipment in terms of the Textile Color Card Association colors.

Mention must also be made of the influence of the graphic arts in color standardization, particularly the *Offset Color Guide* published by the International Printing Ink Division of the Interchemical Corporation. This guide contains over 100 separate test frames (of the same subject) and not only illustrates a large variety of color shades arranged according to dominant color, but also gives the specification for each illustration in terms of both the spectrophotometric and the Munsell color factors in accordance with ASA Standard Z44. This booklet represents a convenient and reliable source of color illustrations for color photographing and like tests. Mention must also be made at this point of the *Three Monographs on Color* published by the same company. These volumes are delightful in addition to being scientifically correct. They should be of interest to scientist and layman alike interested in color in any aspect.

Color Filter Criteria. One of the first items to be investigated is the transmission characteristics of the filters used. To the electrical engineer with communications experience, the mention of the word "filters" brings three questions to mind:

(*1*) What are the actual transmission characteristics in the pass band?

(*2*) What are the attenuation rates at cutoff and at crossover, and where are the points of inflection located?

(*3*) What are the transmission "discontinuities" and irregularities?

The concept of Q is so firmly established in the electrical engineer's mind that he would prefer to think of optical filters in the same manner. Although we have not yet learned how to design optical filters with knobs on them that will permit ready adjustment of their resistance, inductance, and capacitance equivalents, the electrical engineer is not stopped from thinking of their performance in such equivalent terms.

In the transmission of black-and-white films by television, gamma and brightness are controlled by knobs, and transmission may be changed from positive to negative by means of a switch. In the transmission of color films by television, not only are these switches and controls at hand,

but there are also "volume" controls for changing color balance and "bias controls" for changing the gamma of one color component with respect to the others. The electrical engineer who is concerned with television thus is forced to think in electrical terms, since all characteristics of the picture that is being transmitted are reduced to a common electrical denominator.

Sources of Filter Data. Optical filter data are obtained from the catalogs of manufacturers and from such references as the Hodgman-Holmes *Handbook of Chemistry and Physics*, familiar to most students of chemistry. Some of the more important catalogs include:

(*1*) *Glass Color Filters*, Corning Glass Works, Corning, N. Y. (Form C247).

(*2*) *Jena Colored Optical Filter Glasses*, Fish-Schurman Corp., New York (4892E).

(*3*) *Neue Lichtfilterglaser*, Fish-Schurman Corp., New York (5990g).

(*4*) *Wratten Light Filters*, Eastman Kodak Company, Rochester, N. Y. (16th Ed.).

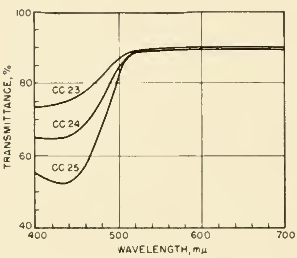


Fig. 117. Transmittance *vs.* **wavelength characteristics of Eastman color compensating filters CC23, CC24, and CC25.**

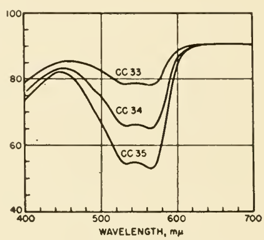


Fig. 118. Transmittance *vs.* **wavelength characteristics of Eastman color compensating filters CC33, CC34, and CC35.**

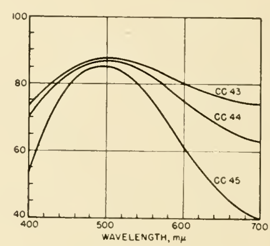


Fig. 119. Transmittance *vs.* **wavelength characteristics of Eastman color compensating filters CC43, CC44, and CC45.**

Data for Filters Used in Kodachrome Duplication. The per cent transmittance—wave length characteristic of the 2B Wratten filter is given in *Wratten Light Filters*, and the characteristics of Aklo filters are given in *Glass Color Filters*, both mentioned above.*

Figure 117 shows the characteristics for the minus-blue series (CC23, CC24, and CC25), Figure 118 shows the characteristics of the minus-

* The two pieces of Aklo glass supplied by Eastman Kodak are 3.2 mm. thick. The data given in the Corning catalog for Aklo numbers 3966 (extra light shade), 3965 (light shade), 3962 (medium shade), and 3961 (dark shade) are for a thickness of 2 mm.

green series (CC33, CC34, and CC35), and Figure 119 shows the characteristics for the minus-red series (CC43, CC44, and CC45).

If these various sets of color compensating filters are compared, significant differences are apparent. Although each set represents a "family," only the minus-blue series seems to fit the "ideal" criterion that attenuation shall take place only in the band for which the filter is rated. Even this series does not have a "square wave" transmission characteristic. It would be unreasonable to expect such a characteristic from the coloring materials available for filter making. Since the differences, though small, are significant, it is well to summarize them.

Minus-Blue Series (CC23, CC24, CC25)

(*1*) One principal absorption wave length-430 mμ.

(*2*) Negligible attenuation in either the minus-green or the minus-red bands.

Minus-Green Series (CC33, CC34, CC35)

(*1*) Two principal absorption wave lengths-530 and 565 mμ.

(*2*) Slightly greater attenuation at 565 mμ than at 530 mμ.

(*3*) Slight attenuation in the minus-blue range (approximately 10% at 430 mμ for CC35).

(*4*) Negligible attenuation in the minus-red range.

Minus-Red Series (CC43, CC44, CC45)

(*1*) Broad band nonsymmetrical transmission centered about 500 mμ.

(*2*) Slight attenuation in the minus-blue band (approximately 15% at 430 mμ for CC45).

(*3*) Greater attenuation at 565 mμ in the minus-green band than at 530 mμ (almost 15%).

(*4*) Appreciably greater attenuation at the longer wave length end of the minus-red band than at the shorter wave length end (approximately one-third greater for CC45 at 700 than at 600 mμ).

Should it be necessary to use other filters for correction purposes it will be found that it is not convenient to compare quickly the published characteristics of filters made by different manufacturers owing to the differences in the manner in which such characteristics are presented. It is hoped that in the future all manufacturers will use standard scales for published data and standard methods of measurement so that optical filters for photographic purposes may be readily compared regardless of their origin. The color compensating filters (CC types) for printing are subtractive; the accuracy of control is very poor in printing compared with additive color printing. Additive color filters may be used in such trichromatic printers as the DeBrie.

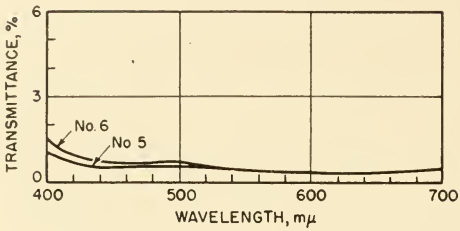


Fig. 120. Transmittance *vs.* wavelength characteristics of developed unexposed Kodachrome. No. 5 is EK 5265 duplicating film, No. 6 is EK 5264 type A film.

Data for Kodachrome Duplicating Film. The film itself can be checked for deviations from the "ideal." Figure 120 shows a per cent transmittance versus wave length characteristic of unexposed developed Kodachrome; for comparison purposes both Type A and duplicating Kodachrome are shown. From these curves it is reasonable to conclude that Kodachrome when unexposed provides a satisfactory neutral gray.

The film can next be checked under simulated operating conditions. Figure 121 shows these characteristics when a fine-grain black-and-white film which is uniformly exposed (EK 5365 exposed and developed to a density of 0.5) is printed on a step-contact printer through the basic set of filters recommended by Eastman Kodak for duplication. These curves show that at the exposure used the neutral gray is reasonably well maintained. In addition, they indicate that although EK 5264 Type A Kodachrome requires less exposure than EK 5265 duplicating Kodachrome, the duplicating film has the smoother curve and should be used whereever possible. Among other reasons for preferring it, is the not unimportant factor that the price is appreciably lower.

Contrast Control. It may well be said that integral tri-pack duplication makes no provision for the purposeful control of contrast. While it

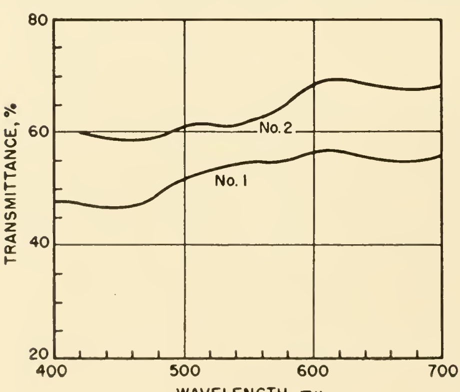


Fig. 121. Transmittance *vs.* wavelength characteristics for Kodachrome duplication of black-and-white film. EK 5365 was uniformly exposed and developed to a density of 0.5; this was printed on EK 5265 (No. 1), and on EK 5264 (No. 2). Lamp at approx. 80 v. (See Fig. 122 for lamp data.)

is true that a decade ago there was little need owing to the limited useful contrast range, subsequent control improvement has brought forth that need.

The problem is a very difficult one. It means the introduction of still another variable into a process where the number of variables is already large compared with commercial black-and-white processes. At first glance, AnscoColor Film would seem to present the possibility in the color developing of the film, but so far there has been little encouragement in this direction. In the case of Kodachrome the need for constant developing is considered very important and it is felt that contrast control is better accomplished in some other manner.

A number of solutions to the contrast problem has been suggested and a certain amount of laboratory experience has been obtained with one possibility-masking film.* So far, the complexities of use are such that it has not been considered suitable for motion picture use although it is well suited for still pictures. It would not seem impossible to incorporate this in the form of an additional sensitized layer in the duplicating raw stock. Such a layer might have the further advantage of being suitable for the sound record, thereby avoiding some of the seemingly insurmountable problems associated with the multi-layer color sound track.

As the increase in contrast due to even a single printing step is quite high, Kodachrome Commercial, a low contrast color positive material, has been introduced as an original material from which duplicates can be made that will have approximately the same contrast characteristics as a Kodachrome original made on Kodachrome Regular.

Ansco has recommended the use of a separate mask optically superimposed. Because of the high order of registration accuracy required, this method is not in wide use now. It is felt that there are also some simpler methods possible that will be commercially satisfactory, despite the fact that a certain amount of sacrifice of color fidelity may be required; one possibility is the use of light sources emitting band spectra rather than a continuous spectrum.

* Masking film when so used is an unexposed sensitized thin film cemented or otherwise attached to the developed original Kodachrome picture. Each scene is given a predetermined exposure in a printer and then developed in a black-and-white developer bath, producing a complementary negative of the picture on the masking film as a mask. When the picture is then printed (with the masking film still attached), the contrast of the original is effectively reduced. (Should an increase in contrast be desired, this might be accomplished by developing the masking film as a reversal. It is rare that an increase in contrast is desired; most duplicated films suffer from excessive rather than too little contrast.)

Production Quality Control of Prints

There is much to recommend the routine testing of every roll of film printed. It is necessary to establish quality control in printing and to maintain control once it has been established. Routine testing is required for every other element entering into the process. Commerical color duplication in Kodachrome is therefore exacting and demanding, yet interesting work.

The starting point is a lamp, the color temperature of which is known.

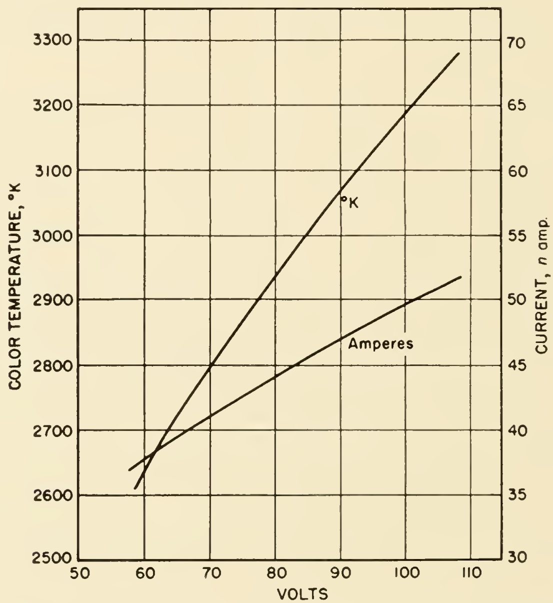


Fig. 122. Volts *vs.* color-temperature and amperes characteristics of 500-w, 105-v, T-10 lamp.

The color temperature is not known, however, unless the limits to which it has been measured are also known. The same electrical testing laboratories that provide recording spectrophotometer services can also determine the current at which a particular lamp will reach the desired color temperature. If a lot of 50 lamps of the same type is tested, the cost for a measurement within a tolerance of $\pm$ 10 K is but a fraction of the cost of the lamp itself. Should seasoning or aging be required, these laboratories can provide such service at very low cost. With such reliable services available at low rates, no commercial laboratory engaged in the

duplication of color film, such as Kodachrome, can afford to be without control aids. Figure 122 shows a color-temperature–voltage–current relationship of a typical 500-w., 105-v. T-10 printing lamp. Other valuable lamp data are found in the bulletin *Mazda Lamps* published by General Electric.

Exposure is most readily measured directly at the printer aperture with the machine stationary; the better grade illuminometers such as the Weston (priced approximately at 100 dollars) are suitable. Indirect methods, such as the use of black-and-white film as a control, are not practicable in most commercial laboratories as they introduce additional variables whose variations are usually unknown.* In using illuminometers and similar direct-measuring instruments, it is necessary to make up suitable jig-adapters so that readings of the instrument will be reproduced without significant personal error. Provision should also be made for periodically calibrating the measuring instruments. It is necessary that the variation in slip of belt-driven printers be known. It is still better to use direct-gear drive with a 3-phase synchronous motor or equivalent to eliminate machine speed variation as a possible source of exposure variation.

The regulation of the current supply for the printing lamp is very important. It is obviously a sheer waste of time and money to calibrate lamps to $\pm$ 10 K when the motor generator or other supply has poor regulation, and other loads are indiscriminately "placed on the line" and "taken off." A simple check is to connect a recording voltmeter to a printer under suspicion, using that printer without current changes meanwhile. Often the local power company will be glad to lend a suitable meter if one is available.

From the user's point of view, Kodachrome duplicating film (EK 5265) is quite consistent. The major variation that occurs is the variation from lot to lot, similar to that occurring in black-and-white materials. With fresh film, the variation in sensitivity from one lot to another appears to be less than one of the smallest compensating filter steps (CC23, CC33, or CC43). The variation in layer sensitivity from one layer to another appears to be likewise small and of comparable order. For film that has aged slightly (for example, less than 6 months old when stored at a constant temperature not over 70 F), there is a slight loss in

* Such indirect methods can be satisfactory if the sensitometric control on black and white is of a superior order compared with usual commercial control. In such cases, however, the direct methods are still more convenient and more precise.

speed and a slight change in color balance, but the sum total of such variations does not appear to exceed the equivalent of the single filter step already mentioned. When film has been improperly stored or is old it is likely to be "off balance" by more than a single filter step. It is prudent to make an exposure and color balance test not only for every emulsion lot of film received, but also on every lot received at different times. A log with the results of such tests quickly shows up not only errors and variations, but also indicates when properly interpreted the magnitude of the exposure variation actually encountered in printing the tests.

Routine testing of filters in the arrangements in which they are used is helpful. The cost for several curves is no more than the price of a single 800-ft. roll of raw film. Testing of this kind is in reality inexpensive quality insurance.

Routine testing of the duplicates made commercially is readily accomplished if a test strip is attached to every roll of preprint material and printed as a part of the routine printing operation. The test strip can be designed to fit whatever situation is required. A simple yet informative test leader might include a few frames of each of the following:

(*1*) A fine-grain silver film (such as EK 5265) uniformly exposed to a density of 1.0.

(*2*) Clear leader (made by running EK 5365 through hypo).

(*3*) The 16-mm Kodak color test chart.

(*4*) Kodachrome printed through a Wratten 49 (blue filter) to yield a color density of 1.0.

(*5*) Same as (*4*) except through a Wratten 61 (green filter).

(*6*) Same as (*4*) except through a Wratten 29 (red filter).

(*7*) A resolving power test chart.

The test strip should be printed at "normal" exposure for the particular lot of raw film.

Sections *1, 2, 4, 5,* and *6* of the strip can be read with an ordinary Eastman densitometer. The results of these readings can be plotted in a "scatter diagram" in accordance with the methods described in ASA Standards for Quality Control, Z1.1, Z1.2, and Z1.3. A check lasting over even a few weeks will indicate where the "tightening-up" process should be applied for quality improvement and in what amounts it should be applied. If more accurate results are required in specific cases, other checks such as per cent transmittance versus wavelength curves may be taken on the pertinent parts of the printed strip.

Conclusion

Integral tri-pack films such as Kodachrome are good materials in good control at the present time. It must be remembered, however, that there is no "perfect" color process. The usual requirements of a color process are:

(*1*) A suitable gray scale.
(*2*) Comparable color scales for the components.
(*3*) Accurate reproduction of color.
(*4*) Good differentiation of color.

Each of these requirements conflicts in some measure with at least one of the other three. Ordinarily *1* and *4* are favored over *3*.

The most recent edition of "Photomicrography" (1944) carries the admonition concerning photometric filters in these words: "There are no colored pigments or dyes actually available for making the three colored components of a picture that do not absorb light outside of their own spectral domain and thus degrade the hues of the final result". Curves are essential in describing the performance of filters for color duplicating purposes.

For convenience, wave lengths shorter than approximately 420 mμ are usually filtered out of the exposing illumination. This is accomplished with the Wratten 2A filter or equivalent. The near ultraviolet and the shorter blue rays increase the exposure in the blue layer, but as it is not practicable to evaluate this exposure accurately by either an illuminometer or by the indirect film method, it is usually better to remove these wave lengths from the light beam. With these wave lengths removed, results are usually more reproducible.

Generally speaking, colors that have components in the filter crossover regions of 500 mμ and 600 mμ are difficult to control for accuracy of color reproduction. In most practical cases good color differentiation will suffice and such filters as the Corning 5120 (light didymium) and its approximate equivalent, BG11, in moderate thicknesses, such as 1 mm. and 2 mm., are often quite useful. These filters are likewise helpful in retaining face and skin detail in a duplicate that is printed from a slightly overexposed original, as well as in the reproduction of certain biological stains and dyes whose absorption points are "unfortunately" located.

It should be remembered that even a "perfect" copy is of little value if the print is not projected properly. The importance of correct illumi-

nation level can hardly be overemphasized. At present, even when screen illumination is in the uppermost range found in practice, it is rarely within 20% of what might be called the optimum value. Because screen illumination is of such a low general order, film laboratories have often deliberately chosen to overexpose duplicates in printing by as much as one-third, thereby wiping out much detail and further aggravating an already serious condition of low resolving power. The magnitude of this effect can be roughly judged by comparing the detail and quality of a Technicolor picture projected in a neighborhood theater with the usual 16-mm projection of a Kodachrome duplicate. Such a comparison is reasonable; several Technicolor releases have been made from 16-mm Kodachrome originals. There are other factors, but these are beyond the scope of this chapter.

Although the method recommended by Eastman Kodak of duplicating Kodachrome is relatively simple and places the major part of the control burden upon the film manufacturer, it is imperative that the commercial laboratory accept its share of the control responsibility knowingly and willingly, and appreciate the importance of process control by applying its basic principles. The control of emulsion quality in manufacture and the control of color developing have reached such a high point that it is no longer possible to indiscriminately "pass the buck" to the film manufacturer if prints do not come up to expectations. We must first learn to control the single parameter of good monochrome successfully before we can expect to be successful with the 3 parameters of integral tri-pack duplication. This is a challenge to all concerned; a rapidly growing industry will be awarded as the prize to those who produce the best product at the lowest price.

Selected Bibliography

Wall, E. J., *History of Three Color Photography.* Am. Phot. Pub. Co., Boston, 1925.

Friedman, J. S., *History of Color Photography.* Am. Phot. Pub. Co., Boston, 1944.

Hardy, A. C., *Handbook of Color Analysis.* Technical Press, Cambridge, 1936.

Evans, R. M., *An Introduction to Color.* Wiley, New York, 1948.

Wright, W. D., *Measurement of Colour.*

Bouma, P. J., *Physical Aspects of Colour.* Philips Research Laboratories, Eindhoven, 1949.

Weigert, *Optische Methoden der Chemie.* Akad. Verlagsgesellschaft, Leipzig, 1924.

Gibb, *Optical Methods of Chemical Analysis.* McGraw-Hill, New York, 1942.

Weissberger, (ed.) *Physical Methods of Organic Chemistry.* New York, Interscience, 1949.

Kendall, O. K., ''16-Mm Film Color Compensation,'' *JSMPE, in press* (1949).
Hanson and Richey, ''Three-color Subtractive Photography,'' *JSMPE, 52,* 119 (Feb. 1949).
Miller, T. H., ''Masking,'' *JSMPE, 52,* 133 (Feb. 1949).
Keith, C. R., ''Inter-society Color Council Symposium,'' *JSMPE, 52,* 156 (Feb. 1949).
Macbeth and Nickerson, ''Spectral Characteristics of Light,'' *JSMPE, 52,* 157 (Feb. 1949).
Foss, C. E., ''Color-Order Systems,'' *JSMPE, 52,* 184 (Feb. 1949).
Guilford, J. P., ''System in Color Preference,'' *JSMPE, 52,* 197 (Feb. 1949).
Forrest, J. L., ''Machine Processing of 16-Mm AnscoColor Film, *JSMPE, 45,* 313 (Nov. 1945).
Clarke, C. G., ''Practical Utilization of Monopack Film,'' *JSMPE, 45,* 327 (Nov. 1945).
Aex, P. S., ''Photoelectric Method for Determining Color Balance of 16-Mm Kodachrome Duplicating Printers,'' *JSMPE, 49,* 425 (Nov. 1947).
Harsh and Friedman, ''One-Strip Color Separation Film in Motion Picture Production,'' *JSMPE, 50,* 8 (Jan. 1948).
Bates and Runyan, ''Processing Control Procedures for AnscoColor Film,'' *JSMPE, 53,* 3 (July 1949).
Brunner *et al.* ''Analysis of Developers and Bleach for AnscoColor Film,'' *JSMPE, 53,* 25 (July 1949).
Braun, T. J., ''Improved Filter Holder for Color Printing,'' *JSMPE, 53,* 36 (July 1949).
Forrest, J. L., ''Metallic Salt Track on AnscoColor Film,'' *53,* 40 (July 1949).
Harsh and Schadlich, ''Laboratory for Development Work on Color Motion Pictures,'' *JSMPE, 53,* 50 (July 1949),
Görisch and Görlich, ''Reproduction of Color Film Sound Records,'' *JSMPE, 43,* 206 (Sept. 1944).
Gage, H. P., ''Color Theories and the Inter-society Council,'' *JSMPE, 35,* 361 (Oct. 1940).
Bruno, M., ''Maps on Microfilm,'' *JSMPE, 41,* 423 (Nov. 1943).
Duerr and Harsh, ''AnscoColor for Professional Motion Pictures,'' *JSMPE, 46,* 357 (May 1946).
Bingham, R. H., ''Sensitometric Evaluation of Reversible Color Film,'' *JSMPE, 46,* 368 (May 1946).
Drew and Johnson, ''Preliminary Sound Recording Tests with Variable Area Dye Tracks,'' *JSMPE, 46,* 387 (May 1946).
Hamly, D. H., ''Robert Ridgway's Color Standards,'' *Science, 109,* 605 (June 17, 1949).
Walsh, J. W. T., ''The Measurement of Coloured Light,'' *Endeavour (London), V,* 142 (Oct. 1946).
Mees, C. E. K., ''Modern Colour Photography,'' *Endeavour, VII, 131* (Oct. 1948).
''The Agfacolor Process—Report PB 79559,'' Office of Technical Services, Dept. of Commerce, Washington, 1949.
Homolka, *Brit. J. Photog., 54,* 136, 196, 216 (1907).
Lewy, German Pat. 250,647 (1909).

Fischer, *Brit. J. Photog., 60,* 595 (1913).
Fischer, Brit. Pat. 15,055 (1912).
''Mazda Lamps—Bulletin 1D-1,'' General Electric Co., Cleveland, 1940.

For further bibliographic material the reader should refer to the following indexes to the *Journal of the Society of Motion Picture Engineers.*

July 1916–June 1930

''Color Photography,'' page 120.
''Patents—Color Photography,'' page 138.
''Tinting and Toning,'' page 152.

January 1930–December 1935

''Color Cinematography,'' page 12.
''Coloring,'' page 13.
''Committee Reports—Color,'' page 13.
''Dufaycolor,'' page 23.
''Filters,'' page 26.
''Hand Coloring,'' page 31.
''Handschiegl,'' page 31.
''Multicolor,'' page 41.
''Psychology of Color,'' page 54.

1936–1945

''Color,'' page 82.
''SMPE Activities—Color Reports,'' page 128

CHAPTER XV

Industrial Applications of Current 16-Mm Sound Motion Picture Equipment

When Edison started his developmental work on motion picture apparatus some 50 years ago, he ventured the opinion that motion pictures would become a most powerful influence over people. We have seen this prophecy come true in a fraction of a century, a really short space of time in the history of man.

Edison also viewed the motion picture as potentially a most important instrument of education. A review of early history, however, shows numerous uncoordinated efforts by many to introduce motion pictures into elementary and other schools in an attempt to establish its place properly and adequately in mass compulsory education quite as much as in other branches. Despite the many advances in application since, motion pictures are still far from having reached their rightful place in bringing to all people the full benefits of films in education. To an unbiased observer, it would seem that there are far too few films and far too few machines being used today. One of the causes is a shortage of funds set aside for such purposes. Teachers seem hesitant to suggest and taxpayers hesitant to approve greatly enlarged budgets for teaching films. One possible reason is that for years motion pictures and entertainment were always synonymous, and they had little in common with education.

Fortunately the use of film in industry has not been retarded to quite the same degree. Manufacturers, despite all that may be said to the contrary, seek to maintain competitive advantage by selling a better product in the marketplace at a lower price. Films have aided in this objective; one of the earliest applications was in selling. Selling films had the double objective of showing the employee how to sell and of encouraging the buyer to increase the size of his purchase. As the performance results of such films could be quickly measured in terms of increased sales and lower cost per sales dollar, industry was quick to embrace this potentially efficient communication tool. The results were quite impressive, so impressive, in fact, that a number of films were pro-

duced of the misguided extravaganza variety that are far better suited to entertainment than to business or to education.

It should be obvious that any communication medium is particularly fitted to specific classes of intelligence transmission; this principle applies no less to the film than to any other communication medium. As we review the films produced by education and those produced by business, we are struck with the similarity of the aims of the two fields and the dissimilarity of the films produced. We are tempted to conclude, if a cryptic summary may be ventured, that business has produced much film and little theory as to how films should be made and used, whereas education has produced much theory and few films in accordance with the established theory. Since the aim of both films is to "put an idea across," it is reasonable for us to extrapolate the experience of one into the field of the other to the mutual benefit of both.

One of the simplest and best reports on the subject of films for educational purposes is that of the Committee on Intellectual Cooperation of the League of Nations, written in 1924. The findings of this Committee may be considered a reference standard through which the efficiency of instructional films may be gaged. The following is a résumé of the report.

(*1*) Slides and motion pictures should be used for maximum effectiveness. As a general rule the use of these two adjuncts is not judiciously proportioned, one oftentimes being used to the complete exclusion of the other. We can no doubt agree that the conclusion of some twenty-five years ago is still a valid one today. Too many projects use but one medium to the complete exclusion of the other.

(*2*) All objects and scenes that the audience is intended to watch and remember in movement should be shown in movement. Still pictures representing objects and scenes that ought to be seen in movement should be banned as giving a distorted impression of the actual facts. While our films are improving in this regard, we still find countless instances where we photograph stationary objects with a motion picture camera and moving objects with a still camera.

A corollary that may reasonably be added at this point is that all objects and scenes that the audience is intended to watch and remember in sound should be shown in sound. Silent pictures representing objects and scenes that ought to be heard in sound should be banned as giving a distorted impression of the actual facts.

(*3*) The screen cannot displace the personal element; it can to some

extent displace printed matter, and it should, in all events, be used in combination with it. The use of the screen in conjunction with text-books and printed matter is still quite undeveloped despite significant advances in teaching methods; its effectiveness when properly used is in the top rank of communication media.

(*4*) The screen should be used in combination with personal contact in "getting the idea across." It should be used at the location where the salesman or teacher ordinarily operates whenever it is of advantage to do so. It should be possible to repeat the picture several times, if necessary; the picture should be definitely constructed in such a manner that it will bear repetition.

Industry has shown a growing tendency to bring the screen to the customer instead of the customer to the screen. This tendency is in the proper direction.

It is not true, however, that films are always constructed in such a manner as to bear repetition, as is particularly necessary in films for instructional purposes. Too often a large number of diverting technical effects such as fancy wipes, dissolves, and the like, have been used in a single reel. Such technical effects do not cover up glaring defects in plot, continuity, and lack of logical presentation that are also usually present. Our technical effects shall aid the story, not make it.

(*5*) The screen cannot be used in the proper manner unless there is very wide distribution of effective yet inexpensive apparatus, so that every user of films can have his own projection equipment. The simplest apparatus to handle will be best, and at the same time there must be no risk of fire. If the screen is to do its proper work the apparatus must quickly become a thing in daily use.

The 16-mm size affords the best means of very wide distribution of effective yet inexpensive apparatus with minimum risk of fire. It is the simplest to handle and makes possible the daily use of the equipment because of its very simplicity and low cost of operation and maintenance. That this is true of equipment for making films as well as of equipment for reproducing films is only now beginning to be appreciated in its broader aspects.

(*6*) The mode of use of the screen must be improved, having regard to the fact that it can act upon the mind of the spectator:

(*a*) By faithful presentation of the subject.
(*b*) By the representation of the subject simplified.
(*c*) By the representation of the subject in sections.

(*d*) By the representation of the subject intensified, magnified, represented, speeded up, slowed down, built up by degrees, or superposed. These different methods must be employed according to a logical scheme, taking into account the subject to be dealt with and the specific character of the audience to which the film is planned to be shown.

"Too often they (the producers) have sold companies on the idea of producing films, not as integrated parts of a well rounded-out program, but as special bits of magic for one-time splurges. Even in the larger efforts it is almost as common for a film to be designed for no particular audience as it is in the case of the film produced by the fly-by-night "Hollywood" director who "has his office in his hat." There is still the feeling among a number of picture purchasers, and to a lesser degree among picture producers, that one magic superspectacle is better than a large number of modest films each telling its complete part of an integrated story.

It is of utmost importance that the *exhibition* plans for a film be fully completed before the first camera exposes the first foot of film. Maximum effectiveness presumes the gearing of the subject matter of the film to the audience.

(*7*) The screen is a valuable means of suggestion; it will be used as a time-saver, often a valuable one, in "putting across" all matters that depend largely on visual memory.

Psychologically, the lighted screen in the darkened room compels concentration upon the material presented. It is not only possible to "put across" details of mechanisms and their operation, but also to explain the coördination of the activities of groups that cannot be observed in the usual course of events. This field is practically a virgin field for industry.

(*8*) In order to economize effort and to save expense in making films, and to derive maximum profit from them, it is advisable to decide definitely beforehand to what extent regular photographing and animation, respectively, are to be used.

Due to the high cost of animation per foot in comparison with regular photographing, animation is used to a much smaller degree than in many cases seems desirable for maximum effectiveness.

If we reëxamine the field of business films as a whole, we are struck with the fact that the external film, in particular, the film developing the customer-to-sales-organization relationship, is widely used. The internal business film is less widely used and still less widely heralded. Many organizations that have used both have found that dollar-for-dollar

the second type usually produces better results wherever it has been tried. The obvious use of the internal film is in sales training, and many organizations have set up photographic departments to make use of the advantages of this type of film.

The well-managed industrial organization is always looking for new opportunities to achieve and maintain competitive advantage. When a unit for the production of internal business films is first organized, its personnel complement is small and its activities few. These few activities are usually related in some manner or other to the selling operation. But when the film production unit gets under way, its scope of activity expands far beyond its original purposes into fields that have little to do with the sales operation *per se.*

An excellent example of this is a pre-war film produced by the Fisher Body Division of the General Motors Corporation showing how container-packed automobile body parts may be advantageously handled by transportation companies between the manufacturing plant and the assembly plant, to the simultaneous profit of both the transportation companies and the Fisher Body Division. This film was produced wholly within the company organization. While it was necessarily photographed in "catch-as-catch-can" manner, the film tells its story forcefully as well as effectively and needs no technical embellishment whatever to establish the straightforward points of the presentation.

The establishment of such internal motion picture departments in industry is now becoming quite common. Some organizations, such as the Fisher Body Division, in the case just cited, prefer to produce the film completely within the organization. Other organizations, such as the Skelly Oil Company with its salesman-training films, prefer to work out the script and shoot the basic material, leaving the editing and scoring work in the hands of a commercial 16-mm film producer. The proper procedure depends upon the circumstances; each has its respective advantages. The 16-mm industry is prepared to supply not only all the necessary equipment but also all production and other services required for all such needs.

The advantages of 16-mm equipment for internal production purposes hardly need repetition here. In 16-mm production equipment as in projection equipment, relative simplicity, portability, freedom from fire risk, and relatively long operating time per pound of film are already well known. The picture quality and the sound quality may be made as good as required. In the case of the sound, for example, the quality may

readily approach that of 35-mm theater reproduction if desired, as has been demonstrated at a recent meeting of the Society of Motion Picture Engineers by J. A. Maurer.

In internal films it is the subject matter that is of predominant importance. Such subject matter does not need and may not even tolerate dramatization; it is best presented in straightforward expository style. Subject matter need not be created and staged; there is an abundance of it to be found in the industrial processes, in the plants, in the men, and in the routines of organization. All people, whether here or abroad, are eager to learn how things are made and what is done in their making. There is far more grass roots good will value obtained from presenting the story of the manufacture of a product that far out-performs and outwears its competitors, than can be obtained by all the glittering superlatives that may be culled from a dictionary.

The all-important qualification of a producer of internal films is an intimate knowledge of the organization for which he intends to produce. He must be thoroughly familiar with its policies, its plans, and its objectives. He must be on a firm footing with the personnel; he must know executives and managers and have their full confidence. Most of all, he must know and understand the various problems existing in the company. Only with qualifications such as these can he expect to make his work appear convincing and authentic.

It would seem difficult to find men answering these requirements anywhere except among the company's seasoned employees. Can such employees become the producers of internal organization films? The answer is definitely "yes"; the required technical ability is readily developed by a person with the necessary aptitude, as anyone familiar with the characteristics of direct 16-mm camera and sound-recording equipment can understand. The technic of the medium is, as a general rule, readily acquired by a person who has the other necessary qualifications.

There are two general classifications of business films for internal use: those that convey a message from management to personnel, and those that convey a message from personnel to management. The films in the former group are primarily instructive; they may therefore be expected to follow the usual four-step instructional method of preparation, presentation, application, and examination. Other media of instruction, such as the lecture, the slide-film, and the printed word, should be integrated parts of the instruction method. Since the films in the latter group are primarily informative, the examination step usually is

not involved in the presentation. The use of other media of communication such as the lecture, printed word, slide-film, and so forth, is also indicated here just as in the case of instructional film.

Figure 123 shows a general outline of films for internal business use. Certain of the applications shown have been widely used; others are still relatively little developed. Most of the classifications can be readily understood by inspection and need little explanation.

A few notes on some of the lesser understood classifications are indicated at this point. These notes deal with the management-to-personnel films on the non-sales-service group.

Interdepartmental Organization. In larger organizations particularly, the loss of the personal touch is a morale factor that should engage the attention of every business manager. Specialization makes such demands

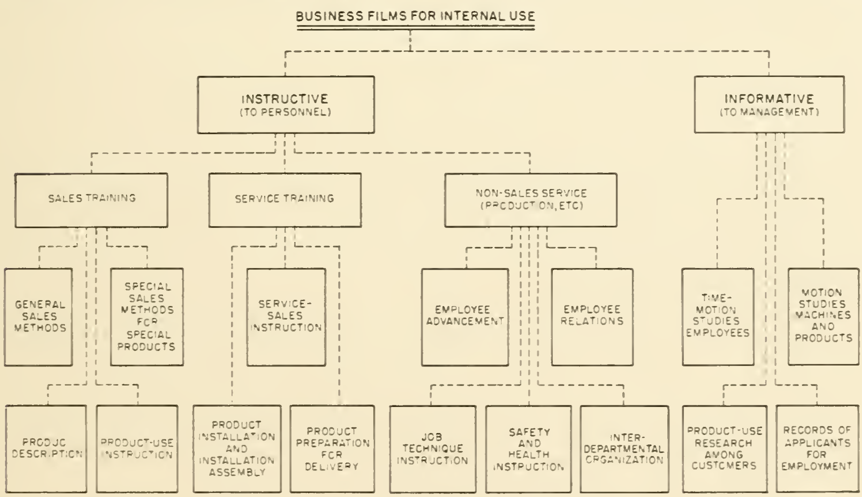


Fig. 123. Applications chart—business films for internal use.

upon the time of a particular individual that it is not only impracticable but usually also impossible to maintain that desirable form of contact. There are numerous companies today where a film outlining the organization of the company would not only reëstablish the personal contact but would also depict clearly the personalities of the men performing the various functions in the organization. This type of film can materially aid the *esprit de corps* and improve the efficiency of the organization.

Safety Promotion and Health Conservation. The loss of time and efficiency of personnel due to sickness and accidents is still a major problem

to industry. Most industrial plants have safety and health programs, varying in scope from weekly bulletin board cartoons to elaborate systems including medical service, health furloughs, and other features. In industrial plants particularly, it has been found that motion pictures are the most graphic means of safety and health education. The work that is now being done in connection with safety training in the mining industry is a typical example. The motion picture makes it possible to show clearly all the details of the little items of carelessness that result in an accident.

Job Technic Training. Job technic training is one of the foremost non-sales uses for internal films. It is not unusual to find that older employees are poor teachers, and, because of possible jealousy of new employees such older employees may even intentionally pass on instruction that is not of the best. The film permits standardized instruction in which no error is introduced through repetition. This standardized instruction may readily be that of the most efficient method of performing a particular task.

New technics must be acquired by old employees, not only to improve their productivity on old products but also to produce new products. If an employee is left to devise his own methods, time-and-motion study—also best done with motion pictures—will show that he usually develops a definitely inferior technic.

Employee Relations. Employee relations is a wide subject that takes in practically all matters that improve the feeling of the employee toward his company. It is now recognized as good management practice to do whatever is possible toward making each employee feel that he is important to his company, and that his work makes him an important member of society and of his community as well.

The ways in which films can contribute to the improvement of such employee relations are almost limitless. Films can be made that give direct educational treatment to such subjects as the aims and problems of the company as well as the soundness of our traditional economic system. Films can be made to provide entertainment for specific employee groups, catering to their particular tastes. Films can be made of employee outings, athletic events, and social events. Films can be made of a documentary or newsreel type depicting existing technics and dealing with local conditions. Such films may be used for historical purposes or for comparing the employee activities in one plant with those in another. Most executives engaged in personnel work can readily visualize a host of other applications.

Employee Advancement. In progressive organization it is a cardinal principle of management that anything that increases the intrinsic value of an employee automatically increases his value to the company. In line with this management principle is the organization principle that a man who fills a particular position should gradually acquire wider and wider experience in the work of the position directly above him. In this manner each man in the organization is progressively relieved of more and more routine work by capable, trained assistants. This condition makes for organization flexibility in that it not only makes possible the replacement of personnel losses resulting from ordinary causes such as sickness and death and the usual labor turnover, but also the replenishment and even expansion of personnel required by market and product expansion, or by emergency causes of whatever nature.

In employee training for advancement, as well as in job technic instruction, the 16-mm sound motion picture finds a logical application. The initial source of basic film material may be film produced for other purposes but edited into an appropriate version, or it may preferably be a film made especially for the purpose. Inasmuch as employee advancement must ordinarily be carried on outside of regular business hours and in addition to the usual duties and routine of the employee concerned, it is doubly important that a wide range of essentials be covered in the most effective and the most efficient manner. Sound-films offer a means of greatly reducing the time allotments for the presentation of facts without sacrificing the quality of instruction.

In almost every broad generalization concerning films, some notable exceptions to the general rule can usually be found. In the field of training films, one such exception is the work of the Photographic Section of the U. S. Army Signal Corps. over a decade ago. In attacking this film problem with its characteristic thoroughness, the Army found that no deviations from the fundamental rules governing training-film production can be tolerated. Each film must be specifically prepared for a particular audience and every effort made to avoid entertainment features or to produce a film suited to what is often called "the general audience." A number of papers on the subject of the Army training film program were presented to the Society of Motion Picture Engineers and all are worthy of very thorough study by anyone concerned with personnel training. The Army, Navy, and Air Forces demonstration films shown before the Society prove that the practical development of the training film has reached an advanced stage quite beyond anything done elsewhere on a scale of appreciable scope.

The second notable exception is best described in an announcement (Feb. 10, 1939) from the Harvard Film Service of the Biological Laboratories of Harvard University concerning film material for the improvement of reading.

The Harvard Film Service in coöperation with the Psycho-Educational Clinic, Harvard University, announces a new type of film material for the improvement of reading.

In brief, these films consist of reading material so presented that successive phrases of the separate lines are exposed rapidly across and down the screen. The film serves as a 'pacer' and the pupil is stimulated to keep up with the rate of exposure. As the training progresses, selections with longer and longer lines are presented thereby gradually increasing the eye span.

During the first half of the current academic year, these films were tested out in an experiment on a group of slow readers among Harvard freshmen. The group met for a 45-minute training period three times a week for eight weeks. The results were as follows: at the close of the experiment, the trained group averaged gains of 41 percentiles on a speed-of-reading test (the Minnesota Speed-of-Reading Test for College Students) and of 24 percentiles on a test of accuracy of reading (Whipple's High-School and College Reading Test) in excess of those made by a non-trained control group. When measured in terms of a difference between initial and final eye-movement records, the average gain in rate of reading of the former was 52 per cent. An analysis of these records in terms of individual measures showed that the average number of fixations per line was reduced from 10.8 to 6.5; the average number of regressions from 1.6 to 0.5.

This material is designed to be run at silent speed (16 frames per second) on any 16-mm projector. It may be used for a single pupil or for a group and requires only a semi-darkened room. Twenty selections averaging 125 feet each, adapted to the senior-high and college levels, together with a teacher's manual and a set of comprehension tests for each film, will be ready for release on March first. . . . Although a smaller number of films may be purchased, the best results will be secured when the complete series for any given level are used. By April first, in time for a two months' training period this year, we shall have ready for release thirty selections for Grades 3 to 5; by next September, a third set for Grades 6 to 9.

Life is daily becoming more complex not only in its social and economic aspects but also in its business aspects. It is imperative that our training methods become more effective from the standpoint of saving time and improving quality of instruction. In addition, training of ever-increasing scope must be made available to an ever-expanding group of our trained citizens. Business has already shown an eager interest in the development, and if present indications can be relied upon, it should not be very long before we shall be hearing of further experimental results of applied programs of internal training development such as is now suggested.

Selected Bibliography

''Camera—Action—Sales,'' Report to Executives, *Business Week* (May 27, 1939), 38.

Seabury, Wm. M., ''Motion Picture Problems—The Cinema and the League of Nations.''

Exton, Wm., Jr., *Audio-Visual Aids to Instruction.* McGraw-Hill, New York, 1948.

Haas and Packer, *The Preparation and Use of Visual Aids.* Prentice-Hall, New York, 1948.

Dale, E., *Audio-Visual Methods in Teaching.* Dryden, New York, 1946.

Devine, J. E., *Films as an Aid in Training Public Employees.''* Report to the Committee on Public Administration, Social Science Research Council, New York.

Lloyd, B., *Science in Films.* Sampson, Low & Marston, London, 1948.

Elliot, G., *Film and Education.* Philosophical Library, New York, 1948.

Sponsored Films in Education. J. Walter Thompson Co., New York.

Sources of Visual Aids for Instructional Use in Schools. Pamphlet No. 80, U. S. Office of Education, Washington, 1941.

U. S. Government Films for School and Industry. Castle Films, New York, 1948.

The Index of Training Films. Business Screen, Chicago, 1946.

The Principal and Audio-Visual Education. National Education Association, Washington, 1948.

Bibliography on Audio-Visual Instructional Materials for Teachers in the Elementary School. Bu. Publications, Teachers College, Columbia Univ., New York, 1948.

Educational Film Guide—A Monthly and Quarterly List of New Films. H. W. Wilson Co., New York.

Selected References on Photographic Visual Aids. Eastmann Kodak Co., Rochester, New York, 1948.

The Film for Your Need. National Film Board of Canada, New York, 1948 (published every few weeks).

Educational Screen. A Magazine (Chicago).

Prosser, W. E., ''Motion Picture Activities of the United States Army,'' *Trans. SMPE, 38,* 355 (May 1929).

Hoorn, F. W., ''Military Training and Historical Films,'' *JSMPE, 21* 337 (Oct. 1933).

Gillette, M. E., ''The Use of Films in the U. S. Army,'' *JSMPE, 26,* 173 (Feb. 1936).

Gillette, M. E., ''Some Psychological Factors in Training Films,'' *JSMPE, 41,* 210 (Sept. 1943).

Goldner, O., ''Problems in the Production of U. S. Navy Training Films,'' *JSMPE, 41,* 146 (Aug. 1943).

Exton, W., ''Developments in the Use of Motion Pictures by the Navy,'' *JSMPE, 41,* 141 (Aug. 1943).

Holslag, R., ''Planning for 16-Mm Production,'' *JSMPE, 41,* 389 (Nov. 1943).

Morkovin, B. V., ''Interrelation of Technical and Dramatic Devices of Motion Pictures,'' *JSMPE, 26,* 270 (Mar. 1936).

For further bibliographic material the reader should refer to the following indexes to the *Journal of the Society of Motion Picture Engineers:*

July 1916–June 1930

January 1930–December 1935

1936–1945

CHAPTER XVI

Television and Film

In recent decades the United States motion picture industry has risen to major rank, bringing its influence to bear not only upon the United States itself but also upon all other parts of the world. For many years, the entertainment motion picture industry has provided more than a fair percentage of the largest incomes in the country for its actors and producers; it has also provided employment for a large number of ordinary people—just as in any other large industry. Technology has reached a high level; it draws upon all associated arts and industries to make it "a going concern." Yet, despite its age (50 years or more) and its high level of technological development (as evidenced by the superb technical smoothness of even the average Hollywood production), its technical literature is surprisingly sparse and spotty. By comparison, no other industry that relies as heavily upon technology has produced so few books.

It may well be that, because the technological processes of the motion picture were the sole concern of a very small, non-expanding, and very highly specialized and elite group of engineers and technicians, its members saw little need of a literature in which books were included. The literature of the technological side of the entertainment motion picture industry is found almost entirely in short papers published in the Journal of a single society, the Society of Motion Picture Engineers. A scientifically trained person who has no knowledge of the motion picture industry would find these papers as pieces of a large jig-saw puzzle in which there is no over-all scheme or guide by which to put the pieces together or to determine whether all the necessary pieces are present.

Farsighted pioneers in the development of the motion picture, such as Edison, although dependent upon the monies received from entertainment films for the income necessary to turn wheels quickly, saw far beyond the entertainment applications into applications of education, advertising, and similar fields, where the knowledge of the technique and the technology must necessarily be widely spread and widely appreciated. World War II saw the realization of these dreams in terms of raw stock consumed; the consumption of raw stock for nonentertainment purposes

far outstripped that for entertainment purposes, reversing the situation that had existed in the industry since its birth. The change appears permanent; 16-mm is now considered symbolic of a new and rapidly growing industry. And now the voracious appetite of 16-mm for raw stock has been still further whetted by the wants of the television industry, which, according to some interested persons, may eventually consume more raw stock than entertainment films and to require much more program material* each year than all Hollywood films produced!

Technologically, television has represented a continuous uphill fight to overcome obstacles that at any particular moment seemed difficult if not impossible of solution. As each such obstacle was reached, a solution was found making the obstacle less important; the effect of the advance is to transfer interest to the next item as the "bottleneck" to be overcome. Progress has been very costly and slow, yet progress is definitely being made. Much research is involved; television research like any other research activity means the investigation of very many projects that are unsuccessful in order to find a very few that are successful. Development is also very slow and very costly; fortunately, much of the development in radar equipment has been directly applicable to television uses. Thanks to radar development, the industry now knows how to build stable high-power, high-frequency transmitters with wide modulation bands, and stable amplifiers and timing circuits with long-life cathode-ray tubes that are capable of withstanding the intense electron beams necessary to produce high brightnesses without "burning" of the picture screen phosphors. War development also financed high-sensitivity camera pickup tubes such as the image orthicon which in today's designs show photographic speeds appreciably better than the ASA 100 speed rating of the fastest commercial films. The manufacturing and engineering branches of the industry have been quick to put these improved components to work in the equipment being developed for commercial use.

Television, like 16-mm motion pictures, suffers from a marked absence of performance standards for the material being transmitted. In sound, for example, the FCC requirements call for a frequency range extending to 15,000 cps, yet it is next to impossible to obtain useful output from a 16-mm commercial film above about 5000 cps or from a 35-mm commercial film above 7500 cps. Despite the known limitations of com-

* NBC reports that it is currently producing an average of 700 hours of movies a year: this is greater than the 1948 movie industry output, which is reported as 369 feature films, or 550 hours.

merical films, it is strange how sound reproduction from film seems so much better in a good theater than the sound* obtained from live pickup in studio television shows. The same may be said for picture quality if due allowance is made for the fact that the films so often televised are so very old. There is a marked dearth of good program material that is especially noticeable in television—because of the tremendous demands imposed by the long transmission schedules. As transmission schedules are further lengthened, it will become even more difficult to keep pace, and new sources of program material must be found. Motion picture films would seem to hold at least a partial solution to this program material problem.

Despite much talk in recent years as to whether films have a place in television, they are widely used. Today, station equipment is not considered complete without motion picture film transmission facilities. There seems little doubt that as television service grows, the use of films in television will grow accordingly.

Films are used in television in a variety of ways. One of the most widely used is the advertising film produced especially for television showing. This type of film is widely used, since the result that appears "on the air" can be carefully checked before transmission to make certain that no editorial errors or "slips" occur in the advertising of a product. One story that is almost legendary points out the importance of such "canned" program material. In a television ad for dog food, a puppy was to be televised while going to a dish containing the dog food being advertised. The dishes were plainly marked "Ours" and "Competitor's." The puppy rushed off in the direction of the competitor's dish and lapped it up with gusto—much to the consternation of the sponsor. Such things can't happen with film; if the film is correct when checked during the rehearsal showing, it is bound to be correct when the film goes "on the air."

Films may be used as "reference recordings" in the same manner that disk records are used for reference recordings in sound broadcasting. In making a reference recording, a motion picture camera is used to photograph the face of a kinescope picture tube to obtain the picture image; the sound may be recorded as a single-system record on the same film, or by any one of a number of sound recording means that can be

* Loudspeakers in television receivers are no better than in radio sets. Audio amplifiers in many are likewise no better than their radio counterparts—especially from the standpoint of distortion.

synchronized with the picture film. Eastman Kodak and others have developed 16-mm picture cameras that are being used for this purpose.

Films may be used at the receiving end to obtain a bright, large-screen picture that cannot be obtained directly with television equipment without excessive geometric distortion, if at all. The technique consists of photographing the face of a picture receiving tube, developing the film, and projecting the film in a conventional motion picture projector. Dumont (affiliated with Paramount) has used this technique for showing a prizefight in a motion picture theater.

The most obvious is the use of motion picture films made for motion picture purposes. Films may be either 35-mm or 16-mm; the latter seems to be the more common.

Artistic Relations of Television and Motion Pictures

If television is thought of as a newly developed art form, it is reasonable to expect it to draw upon all prior art forms. The motion picture draws upon the art of painting and static representation as found in still pictures, adding the representations of movement that are the peculiar province of the motion picture. Television likewise draws upon the experience of both; and since its equipment provides the possibility of readily obtaining many dramatic technical effects very quickly and very easily, it is often limited more by the physical coordination of the operators rather than by the amount of time necessary to produce the effect. There seems little doubt that in future each medium will learn from the other.

If television is thought of merely as a means of transmission, we are reminded that television, like the motion picture, is "the application of engineering equipment to an art." The equipment is merely the tool of the artist; if the tool is good and "easy to use," the artist is little hampered in his self-expression. Unfortunately, there are other kinds of tools; some are good yet "hard to use," some are poor and "easy to use," still others are poor and "hard to use." Each condition places a different kind and amount of restraint upon the artist seeking self-expression.

From the point of view of the audience seeing the show, the backstage mechanics and props that produce the illusion become better as they become more and more subordinated to the subject matter being portrayed. Ideally, their existence should be quite unnoticed. If two pictures are of equal size and quality, one transmitted by television and the other projected as a motion picture, it makes little difference to the

audience what technical arrangements are used to provide the images. At present, the advantage is with the motion picture, since television images are small* and of poor detail by comparison. It should be remembered that natural viewing by persons with normal vision provides sharp images with much detail; fuzzy images with poor detail tend to destroy the desired illusion and interfere with normal vision.

Technical Relations of Television and Motion Pictures

Film Scanning. Standard black-and-white television transmission calls for a line-by-line scanning of each picture frame to be transmitted. The present television frame frequency is 30 per second. The scanning is interlaced 2 to 1. The number of lines per frame is 525; no doubt this will be increased in the not-too-distant future.

In pickup, as in reproduction, the picture is scanned as a series of horizontal parallel lines from left to right (as the viewer faces the reproducing cathode-ray tube or screen). At the end of a scanned line, the trace returns quickly from left to right. The odd lines of the picture (1, 3, 5, 7, etc.) are scanned first; when the right-hand edge of the bottom of the frame is reached, the trace quickly returns to the top left side where it begins scanning the even lines (2, 4, 6, 8, etc.) of the frame. The alternate scanning of the odd picture lines and the even picture lines is called 2-to-1 interlace; the purpose of interlacing is to reduce flicker viewed on the reproducing cathode-ray tube.

It cannot be assumed that the choice of any or all picture transmission parameters necessarily represent the very best possible. The use of 30 frames per second as the television frame frequency, as one example, would seem to have little scientific justification today. It would seem, rather "a cure for a disease that no longer exists." About two decades ago it was hoped that the 60-cycle power line might be relied on for frame synchronization; accordingly, the frame frequency chosen was a submultiple of 60. Technical difficulties such as phasing and frequency drift were so serious that the power line synchronizing idea was abandoned; synchronization pulses are now transmitted as an essential part of the signal. There would seem to be no more justification for the selection of 30 frames per second than for any other. Because of the artistic relationships of the motion picture and television, there would be far more just justification for the selection of a multiple of 24 frames per

* There is unmistakable evidence that the buying public is beginning to consider the 10-inch tube television set too small despite its "loss leader" price.

second; that frame frequency has been standardized internationally for sound films in both 35-mm and 16-mm.

Apertures and Shapes. The shape of the television frame is substantially the same as that of motion picture, since the standard aspect ratio (width-to-height ratio) is 4 to 3. Composition for television photographing should be little different from that for motion pictures if provision is made for a greater percentage of closeups than longshots. Ideally, it would seem that there should be a much higher percentage of closeups than found in the average 16-mm film.

Generally speaking, it is a good idea to compose pictures within the motion picture frame in such manner that most of the detail of interest is located farther from the edges of the picture than is customary for motion pictures. Although camera apertures and projector apertures have been standardized for 16-mm, this standardization does not carry over accurately when 16-mm films are transmitted by television.*

* A situation bordering on a minor technological chaos momentarily faces the unwitting television set buyer in the matter of the size and shape of the picture provided by the set that he proposes to buy. When he looks at competitive sets, it seems reasonable for him to assume that the one that he chooses will provide him with substantially all the picture image that is transmitted as a part of the standard signal. The primary difference that he expects to find is a difference in picture size only; manufacturers' and sales advertising makes him acutely conscious of the size differences (in terms of square inches) and the price differences of the competing receivers.

Commercial sets presently marketed range from a directly viewed 3-inch tube to a projected image of about 18 by 24 inches; in the latter case the image is projected on a translucent screen. The number of projection receivers sold at present is still small relative to the directly-viewed tube type; prices are still too high for a very big market.

It is obvious that the manufacturers of sets providing small pictures are at a serious marketing disadvantage as the images are small, and the detail often seems noticeably poorer when viewed in the user's home. If the standard aspect ratio is to be adhered to, the maximum picture height is only 3/5 of the tube diameter, and the maximum picture width is only 4/5 of the tube diameter. Thus a receiver using a 5-inch tube can not provide a picture larger than 3 by 4 inches if the standard aspect ratio is retained.

In a number of smaller sizes (particularly for tube diameters of 10 inches and less), manufacturers have unwisely chosen to "cheat on the picture" by providing an arbitrarily selected image different from the standard. Five or more manufacturers, including Zenith, Garod, Hallicrafters, Tele-Tone, and Belmont, provide circular pictures; in all of these the circle represents a circle of diameter smaller by some unknown amount than the smallest dimension of the transmitted image, namely, its height. Over 20 manufacturers (Philco, Scott, Andrea, Packard-Bell, Emerson, Olympic, Stromberg-Carlson, U.S. Televsion, etc.) provide "expanded" pictures—that cut

Ordinarily, there are two independent sets of adjustments for picture height and width, one for the transmitter and one for the receiver. Very often the adjustments in transmission are not accurately made; because of the curvature of the face of the cathode-ray receiving tube which often results in appreciable geometric distortion of the picture at the edges, the vertical and horizontal scanning controls are often "turned up" to the point where a substantial portion along the edges of the picture does not appear on the face of the tube at all but is cut off. At present, it can be considered a fairly safe rule to keep significant picture detail within about 80% of the projector aperture area.

Resolving Power. The methods of determining resolving power in motion pictures and in television, although similar in principle, differ in detail. In a line test chart with equal spacings between succeeding lines, the practice in television counts as lines both the lines themselves and the spaces between them; motion picture practice counts only the lines. Therefore, to translate "television lines" to "motion picture lines," it is necessary to divide the former by 2. Thus, a 525 line television picture provides a theoretical resolving power of 525/2 divided by 10 mm. (the height of the equivalent film gate) or 26 lines per millimeter (motion picture lines). If in the case of present standard transmission it is assumed that an increase in film resolving power is needed to offset the slower frame frequency of motion pictures, an increase in the ratio

---

off a major portion of the outer frame area to permit magnification of the central portion of the screen. It is fortunate in many cases that the set owner can omit picture expansion by merely ignoring the button or knob that controls it. It is respectfully urged that television set manufacturers review the history of professional and of amateur motion pictures to extrapolate the experiences of these fields directly into television, if the economic waste due to impulsive engineering decisions without benefit of standardization is to be avoided.

There would seem to be little reason for an aperture sensibly different from the standard motion picture projection aperture. Despite this, Zenith apertures are circular, Philco and Olympic apertures have rounded ends (somewhat similar to the ends of the negative perforation that the motion picture industry has been hoping to eliminate as outmoded), while the General Electric aperture has curved corners comparable with the corners or a rounded 35-mm projection aperture. (The General Electric aperture is the nearest approach to the standard motion picture aperture of the last sets mentioned.) To "cheat on the picture," manufacturers of circular picture receivers (such as Zenith, etc.) have chosen to put the circle of the tube within the rectangle of the picture, rather than to put the rectangle of the picture within the circle of the tube. If, for example, Zenith and G.E. make receivers with an identical type of 10-inch tube, Zenith can claim the full tube-face area of 78½ sq. in., while G.E. would be limited to only 48 sq. in. Such trade practices encourage improper advertising.

of 30/24 would be needed; the (motion picture lines) resolving power required is 33 lines per millimeter. 16-mm films can readily provide resolving power of this order; release print black-and-white raw stock is currently rated at 90 lines per millimeter. As in the case of films for 16-mm projection, care in film processing is necessary if the required resolving power is to be retained in release prints to be used for television transmission.

Special Transmission Characteristics. Commercial television transmission equipment is capable of using film with negative picture images and transmitting it in such manner that conventional positive picture images are produced at the receivers. This can be accomplished just as readily as conventional positive transmission; it is called negative transmission. There is no technical equivalent in films; the nearest similar non-electrical arrangement is the dark-field *vs.* light-field microscope illumination systems common in the microscopy of biology and metallography.

Density and Contrast Characteristics. The density and contrast characteristics required of release prints of picture for television transmission seem to differ but little in a practical way from good motion picture prints projected with standard screen illumination levels in the order of 10 ft.-lamberts. Theoretical considerations derived from the known characteristics of pickup tubes, such as the iconoscope, and receiving tubes, such as the kinescope, would appear to show some contrast deviations. At the present state of the art, these do not seem to be of much practical significance. Just as in the case of motion pictures, some stations prefer light prints where the projector illumination level is low, or similar factors peculiar to the particular equipment obtain.

In the case of negative transmission, conventional motion picture negative and duplicate negative raw stocks are not well suited to television transmission due to the contrast characteristics of the pickup and the receiving tubes. The special raw stocks supplied by films manufacturers especially for this purpose should be used; should any major change occur in the contrast characteristics of the receiving system, such as a radical change in the contrast of the tube phosphors used, it might be well to review once again the over-all contrast characteristics of the television transmission system. Such major change does not appear to be on the horizon at present, but the possibility of it should not be overlooked.

Photographing Television Images and Transmitting Film Images. The use of different frame frequencies for television and for motion

pictures is something of a nuisance and usually makes it necessary to use more complicated arrangements than would be the case if the same frame frequencies were used. The ratio between the television frame frequency and the motion picture frame frequency is 5 to 4—a difficult ratio to handle in a straightforward way in equipment design. In essence, what is necessary for television transmission from films is to derive 5 television frames from every 4 motion picture frames; for photographing motion pictures derived from television signals it is necessary to derive 4 motion picture frames from every 5 television frames.

Several machines are on the market for deriving suitable television signals of 30 frames per second suitably interlocked with the television transmitting system from motion picture film of 24 frames per second. All have more or less complicated arrangements to accomplish this; in most cases a storage-type transmission tube, such as an iconoscope, is used in preference to a direct transmission tube, such as a dissector. An earlier form of system used an arc lamp as the light source, cutting off the light at the appropriate times by means of a special shutter arrangement; this was manufactured by General Electric. Another arrangement also developed by General Electric used a flashlamp as a light source; in this latter arrangement the illumination interval could be made quite short, and the amount of film heating kept to a minimum for the illumination actually used.

Photographing television images is a more special problem. One simple arrangement for accomplishing this is to use a "wild" camera that has a large shutter-opening time. The disadvantage of this arrangement is that frame lines and fuzzy pictures appear in the projected film as a "beat note" between the television frequency of 30 frames per second and the frequency of 24 frames per second. The results may be somewhat more satisfactory if the camera is speeded up to 30 frames per second; in this case the projected film will show a thin "frame line" drifting slowly upward or downard through the picture as the television frequency and the camera drive frequency drift with respect to one another. For commercial purposes, electrical interlock of the photographing camera with the television signals by means of the synchronizing pulses of the signal would seem imperative.

As yet there is relatively little commercial equipment available on the open market to accomplish either 30-frames-per-second or 24-frames-per-second photographing in satisfactory interlock. This has of course been done when films are used at the receiving end to obtain pictures large enough for projection to audiences in a motion picture theater.

Sound. It should not be entirely unexpected that sound transmitted from 16-mm combination release prints will often be "not up to network standards." Since there are no over-all sound characteristics or sound quality standards for motion picture film for television, there is no more assurance that sound quality of a combination release print will be satisfactory than for picture quality. In the absence of a check of a particular film by a television technician or engineer familiar with transmission quality, it is reasonable to believe that if the quality of a film is very good when measured by current motion picture performance levels, it will probably be satisfactory for television transmission.

Standardization. As a practical matter, television operating organizations would do well to push aggressively for national standardization through the American Standards Association of the technical characteristics of television projection equipment and of release prints. Without such standardization, it is likely that no two films to be transmitted will look alike in picture quality, or sound alike in sound quality. Informal standardization of this kind has been accomplished for over a decade among the major Hollywood motion picture companies for their 35-mm films run in theaters; there is even a reference sound projection characteristic for theater equipment that, despite its known shortcomings, has been quite effective in maintaining uniformity of sound quality among the many theaters. A sample 35-mm picture and sound test reel has been available for more than a decade; it has short excerpts of representative scenes from most of the major studios. This reel is brought up to date periodically as improvements in quality are made. This 35-mm reel and its 16-mm counterpart are currently available through the Society of Motion Picture Engineers.

Once reference sound and picture characteristics have been determined for television films, it should be possible to standardize upon a reference 16-mm sound film projector that may be used for previewing films to be checked for television transmission. Such a machine will act as a tool by which the television film program director of a station can determine whether or not the pictorial quality and the sound quality of a submitted film is satisfactory for transmission without actually "piping" it into the television equipment. Television is due for further accelerated growth, and the 16-mm sound motion picture is technologically and artistically prepared to grow with it. The standardization of 16-mm projection equipment and film characteristics will do much to cause such growth to occur in the most economical and quickest manner

and provide even better performance at still lower cost to the ultimate consumer—the avowed object of voluntary standardization and of mass production methods.

Selected Bibliography

Maloff and Epstein, *Electron Optics in Television.* McGraw-Hill, New York, 1938.

Jacobs, F., *Fundamentals of Optical Engineering.* McGraw-Hill, New York, 1943.

Fink, D. G., *Principles of Television Engineering.* McGraw-Hill, New York, 194X.

Zworykin and Morton, *Television, the Electronics of Image Transmission.* Wiley, New York, 194X.

''Theater Television,'' *JSMPE, 52,* 268 (March 1949).

''Television Progress,'' *JSMPE, 51,* 228 (Sept. 1948).

General

Goldsmith, A. N., ''Theater Television—A General Analysis,'' *JSMPE, 50,* 95–122 (Feb. 1948).

Wolfe, W. V., ''Report of the SMPE Committee on Progress,'' *JSMPE, 48,* 304–317 (April 1947).

''Statement of SMPE on Revised Frequency Allocations,'' *JSMPE, 48,* 183–203 (March 1947).

Isaac, L. B., ''Television and the Motion Picture Theater,'' *JSMPE, 47,* 482–487 (Dec. 1946).

Rose, A., ''A Unified Approach to the Performance of Photographic Film, Television Pickup Tubes, and the Human Eye,'' *JSMPE, 47,* 273–295 (Oct. 1946).

DuMont, A. B., ''The Relation of Television to Motion Pictures,'' *JSMPE, 47,* 238–248 (Sept. 1946).

Larsen, P. J., ''Report of the Committee on Television Projection Practice,'' *JSMPE, 47,* 118–120 (Aug. 1946).

Rose, A., ''Photographic Film, Television Pickup Tubes, and the Eye,'' *Intern. Proj.* (May 1946).

''Technical News,'' *JSMPE, 46,* 81 (Jan. 1946).

Austrian, R. B., ''Some Economic Aspects of Theater Television,'' *JSMPE, 44,* 377–386 (May 1945).

Larsen, P. J., ''Statement Presented before the Federal Communications Commission Relating to Television Broadcasting,'' *JSMPE, 44,* 123–128 (Feb. 1945).

''Technical News,'' *JSMPE, 43,* 303–304 (Oct. 1944).

Miner, W. C., ''Film in Television: Television Production as Viewed by a Radio Broadcaster,'' *JSMPE, 43,* 79–93 (Aug. 1944).

Cooper, W., ''Film in Television: Television Production as Viewed by a Motion Picture Producer,'' *JSMPE, 43,* 73–79 (Aug. 1944).

''Television Report, Order Rules, and Regulations of the Federal Communications Commission,'' *JSMPE, 37,* 87–98 (July 1941).

''Report of the Television Committee'' (Flicker, Visual Fatigue, Bibliography), *JSMPE, 35,* 569–584 (Dec. 1940).

Baldwin, M. W., ''The Subjective Sharpness of Simulated Television Images,'' *Bell Sys. Tech. Jour., 19,* 563 (Oct. 1940).

Goldmark, P. C., and J. N. Dyer, ''Quality in Television Pictures,'' *JSMPE, 35,* 234–254 (Sept. 1940).

Skellett, A. M., ''Transmission System of Narrow Band-Width for Animated Line Images,'' *JSMPE, 33,* 670–677 (Dec. 1939).

Schubert, G., W. Dillenburger, and H. Zschau, ''Das Zwischen Film verfahren,'' *Fernsch A. G. Hausmitteilungen, 1,* Part I, 65 (April 1939); Part II, 162 (Aug. 1939); Part III, 201 (Dec. 1939).

Moller, R., and G. Schubert, ''Zehn Jahre Fernsehtechnik,'' *Fernsch A. G. Hausmitteilungen, 1,* 111 (July 1939).

''Report of the Television Committee,'' *JSMPE, 33,* 75–80 (July 1939).

Beers, G. L., E. W. Engstrom, and I. G. Maloff, ''Some Television Problems from the Motion Picture Standpoint,'' *JSMPE, 32,* 121–139 (Feb. 1939).

Blumlein, A. D., C. O. Browne, N. E. Davis, and E. Green, ''The Marconi-EMI Television System,'' *J.I.E.E., (London),* p. 758 (Dec. 1938).

Ives, H. E., ''Transmission of Motion Pictures over a Coaxial Cable,'' *JSMPE, 31,* 256–273 (Sept. 1938).

Strieby, M. E., ''Coaxial-Cable System for Television Transmission,'' *Bell Sys. Tech. Jour., 17,* 438 (July 1938).

''Television Demonstration at the Fall Convention,'' *JSMPE, 29,* 596–603 (Dec. 1937).

''Television from the Standpoint of the Motion Picture Producing Industry,'' *JSMPE, 29,* 144–149 (Aug. 1937).

Beal, R. R., ''RCA Developments in Television,'' *JSMPE, 29,* 121–144 (Aug. 1937).

Goldsmith, A. N., ''Television and the Motion Picture Theater,'' *Intern. Proj.,* May 1935.

Schade, O. H., ''Electrooptical Characteristics of Television System,'' Part I, ''Characteristics of Vision and Visual Systems,'' *RCA Rev., 9,* 5 (March 1948); Part II, ''Electrooptical Specifications for Television Systems,'' *RCA Rev., 9,* 245 June 1948).

Television from Film

Boyer, M. R., ''Test Reel for Television Broadcast Stations,'' *JSMPE, 49,* 391–395 (Nov. 1947).

Little, R. V., ''Film Projectors for Television,'' *Intern. Proj.,* May 1947.

Little, R. V., Jr., ''Film Projectors for Television,'' *JSMPE, 48,* 93–111 (Feb. 1947).

Meschter, E., ''Television Reproduction from Negative Films,'' *JSMPE, 47,* 165–182 (Aug. 1946).

Cook, E. D., ''General Electric Television Film Projector,'' *JSMPE, 41,* 273–292 (Oct. 1943).

Fuller, R. B., and L. S. Rhodes, ''Production of 16-Mm Motion Pictures for Television Projection,'' *JSMPE, 39,* 195–202 (Sept. 1942).

Jensen, A. G., ''Film Scanner for Use in Television Transmission Tests,'' *Proc. I.R.E., 29,* 243–250 (May 1941).

Lubcke, H. R., ''Photographic Aspects of Television Operations,'' *JSMPE, 36,* 185–191 (Feb. 1941).

Wolcott, C. F., ''Problems in Television Image Resolution,'' *JSMPE, 36,* 65–82 (Jan. 1941).

Campbell, R. L., ''Television Control Equipment for Film Transmission,'' *JSMPE, 33,* 677–690 (Dec. 1939).

Goldmark, P. C., ''Continuous Type Television Film Scanner,'' *JSMPE, 33,* 18–26 (July 1939).

Engstrom, E. W., G. L. Beers, and A. V. Bedford, ''Application of Motion Picture Film to Television,'' *JSMPE, 33,* 3–18 (July 1939); *RCA Rev., 4,* 48 (July 1939).

Bamford, H. S., ''Non-intermittent Projector for Television Film Transmission,'' *JSMPE, 31,* 453–462 (Nov. 1938).

Thöm, K., ''Neuer mechanischer Filmabtaster,'' *Fernseh A. G. Hausmitteilungen, 1,* 24 (Aug. 1938).

Ives, H. E., ''A Multi-channel Television Apparatus,'' *Bell Sys. Tech. Jour., 10,* 33 (Jan. 1931).

Fraser, R. M., ''Motion Picture Photography of Television Images,'' *RCA Rev., 9,* 202 (June 1948).

White, C. F., and M. R. Boyer, ''A New Film for Photographing the Television Monitor Tube,'' *JSMPE, 47,* 152–165 (Aug. 1946).

Albin, F. G., ''Sensitometric Aspect of Television Monitor-Tube Photography,'' *JSMPE, 51,* 595–613 (Dec. 1948).

Boon, J. L., W. Feldman, and J. Stoiber, ''Television Recording Camera,'' *JSMPE, 51,* 117–127 (Aug. 1948).

Goldsmith, T. T. Jr., and H. Milholland, ''Television Transcription by Motion Picture Film,'' *JSMPE, 51,* 107–117 (Aug. 1948).

Film from Television

Cherry, W. H., ''Colorimetry in Television,'' *RCA Rev., 8,* 427–460 (Sept. 1947); *JSMPE, 51,* 613–643 (Dec. 1948).

Kell, R. D., ''An Experimental Simultaneous Color-Television System, Part I, Introduction,'' *Proc. I.R.E., 35,* 861–862 (Sept. 1947).

Sziklai, G. C., R. C. Ballard, and A. C. Schroeder, ''Part II, Pickup Equipment,'' *Proc. I.R.E., 35,* 862–871 (Sept. 1947).

Wendt, K. R., G. L. Fredendall, and A. C. Schroeder, ''Part II, Radio-Frequency and Reproducing Equipment,'' *Proc. I.R.E., 35,* 871–875 (Sept. 1947).

Statements and Exhibits of CBS and RCA at FCC Hearing on Color Television, December 9, 1946.

UHF Television Systems, Reports by RMA Committees, Data Bureau, RMA, November 26, 1946.

Interim Report, UHF Color Television, RTPB Panel 6, RMA Television Systems Committee, Data Bureau, RMA, November 25, 1946.

''Simultaneous All Electronic Color Television,'' *RCA Rev., 7,* 459 (Dec. 1946).

Kell, R. D., G. L. Fredendall, A. C. Schroeder, and R. C. Webb, ''An Experimental Color Television System,'' *RCA Rev., 7,* 141 (June 1946).

Goldmark, P. C., J. N. Dyer, E R. Piore, and J. M. Hollywood, ''Color Television— ''Color Television—Part II,'' *Proc. I.R.E., 31,* 465–479 (Sept. 1943).

Goldmark, P. C., J. N. Dyer, E. R. Piore, and J. M. Hollywood, ''Color Television—Part I,'' *Proc. I.R.E., 30,* 162–182 (April 1942).

Goldmark, P. C., J. N. Dyer, E. R. Piore, and J. M. Hollywood, ''Color Television,'' *JSMPE, 38,* 311–352 (April 1942).

Marchant, F. W., "New Baird Color Television System," *Telev. and Short Wave World, 12,* 541 (Sept. 1939).

Baird, J. L., "Color Television," *Telev. and Short Wave World,* p. 151 (March 1938).

Ives, H. E., "Television in Color from Motion Picture Film," *J. Opt. Soc. Am., 21,* 2 (Jan. 1931).

Ives, H. E., and A. L. Johnsrud, "Television in Colors by a Beam Scanning Method," *J. Opt. Soc. Am., 20,* 11 (Jan. 1930).

Erde, B., "Color-Television Film Scanner," *JSMPE, 51,* 351–373 (Oct. 1948).

For further bibliographic material the reader is referred to the following indexes to the *Journal of the Society of Motion Picture Engineers.*

July 1916–June 1930

"Television and Telephonic Transmission of Pictures," page 152.

January 1930–December 1935

"Television and Telephonic Transmission of Pictures," page 67.

1936–1945

"SMPE Activities, Television Reports," page 131.

"Television," page 151.

APPENDIX A

(ASA Z 22. 56–1947)

Nomenclature for Motion Picture Film Used in Studios and Processing Laboratories

1. General

1.1 Motion Picture Film. Motion picture film is a thin flexible ribbon of transparent material having perforations along one or both edges and bearing a sensitized layer or other coating capable of producing photographic images.

NOTE: The term "film" may be applied to unexposed film, to exposed but unprocessed film, and to exposed and processed film.

1.1.1 ***Raw Stock.*** Raw stock is film which has not been exposed or processed.

1.1.2 ***Film Base.*** Film base is the transparent or nearly transparent material upon which a photographic emulsion is coated; namely, the support for the emulsion in photographic film.

NOTE: All 35-mm film is usually understood to be a flammable base (nitrate), unless otherwise specified.

1.1.2.1 *Safety Base.* Safety base is the slow burning film base used in motion picture film.

NOTE: At the present time, safety base and acetate base are synonymous and 16-mm film manufactured in the United State is of this form. All safety base must comply with American Standard Definition for Motion Picture Safety Film, Z22.31-1946.

1.1.3 ***Film Perforations.*** Film perforations are the regularly and accurately spaced holes that are punched throughout the length of motion picture film. These holes are engaged by the teeth of various sprockets and pins by which the film is propelled and positioned as it travels through cameras, processing machines, projectors, and other film machinery.

1.1.3.1 *35-Mm Negative Perforation.* A 35-mm negative perforation is the perforation used for negative and some special-purpose 35-mm films.

NOTE: It is a perforation with sharp corners, curved sides and a straight top and bottom, and its dimensions are as shown in American Standard for Cutting and Perforating Negative Raw Stock, Z22.34-1944 or latest revision thereof.

1.1.3.2 *35-Mm Positive Perforation.* A 35-mm positive perforation is the perforation used for positive 35-mm film.

NOTE: This perforation is rectangular in shape with fillets in the corners, and its dimensions are as shown in American Standard for Cutting and Perforating Dimensions for 35-Millimeter Motion Picture Positive Raw Stock. Z22.36-1947, or the latest revision thereof.

1.1.3.3 *16-Mm Perforation.* A 16-mm perforation is the perforation which is used in all 16-mm film.

NOTE: This perforation is rectangular in shape with fillets in the corners, and its dimensions are as shown in American Standard for Cutting and Perforating Dimensions for 16-Millimeter Sound Motion Pictures Negative and Positive Raw Stock, Z22.12-1947, or the latest revision thereof.

1.1.4 ***Fine-Grain.*** Fine-grain is the term used to designate film emulsions in which the grain size is smaller or finer than in the older type emulsions commonly employed prior to about 1936.

NOTE: This term is relative as there is a wide variation in grain size among various fine-grain films. It is probable that the term will become obsolete when all film emulsions become fine grain. There is no inverse term such as coarse grain.

1.2 Direct Play-Back Positive. A direct playback positive is a sound film which is so originally exposed that upon development in a single developer bath, the resulting image is in positive form available for normal sound reproduction.

NOTE: It is often a variable-area sound record.

1.3 Dupe (Duplicate) Negative. A dupe (duplicate) negative is a negative film that is produced by printing from a positive.

NOTE: A dupe negative is used for producing prints which are, in effect, duplicates of prints which might be made from the original negative.

1.3.1 ***Temporary Picture Dupe Negative.*** A temporary picture dupe negative is a low-quality dupe negative and is made on positive stock.

NOTE: It is used to make low-quality prints for use in editing. It usually contains picture only, but may also have the sound track on the same film.

1.3.2 ***Print from a Temporary Picture Dupe Negative.*** A print from a temporary picture dupe negative is a low-quality print made from the temporary picture dupe negative.

1.4 Image (Photographic). An image is any photographically obtained likeness on a film emulsion.

1.4.1 ***Latent Image.*** A latent image is the invisible image registered on a photographic emulsion due to the reaction produced in the emulsion by exposure to light.

NOTE: This image becomes visible after development.

1.4.2 ***Picture Image.*** A picture image is a photographically obtained likeness of any object on photographic film.

1.4.3 ***Sound Image.*** A sound image is a photographically obtained sound track or sound record.

1.4.4 ***Negative Image.*** A negative image is a photographic image in which the values of light and shade of the original photographed subject are represented in inverse order.

NOTE: In a negative image, light objects of the original subject are represented by high densities and dark objects are represented by low densities.

1.4.5 ***Positive Image.*** A positive image is a photographic replica in which the values of light and shade of the original photographed subject are represented in their natural order.

NOTE: In a positive image, the light objects of the original subject are represented by low densities and the dark objects are represented by high densities.

1.5 Synchronism. Synchronism is the relation between the picture and sound films with respect either to the physical location on the film or films, or to the time at which corresponding picture and sound are seen and heard.

1.5.1 ***Projection Synchronism.*** Projection synchronism is the time relation between picture and corresponding sound in a projection print.

NOTE: Correct projection synchronism is indicated by exact coincidence of picture and sound as seen and heard. To attain this result, it is necessary to place the sound track 20 frames ahead of the center of the corresponding picture for 35-mm film and 26 frames ahead of the center of the corresponding picture for 16-mm film, since sound motion picture projection equipment is designed for projection synchronism with this relationship existing between the locations of the projected picture and corresponding sound.

1.5.2 ***Editorial Synchronism.*** Editorial synchronism is the relationship between the picture and sound film during the editorial processes.

NOTE: During the editorial process, the sound track and corresponding picture, whether on the same or separate films, are kept in alignment and not offset as for projection. Thus, cutting a picture and sound can be a simultaneous operation. Many composite release negatives are supplied in editorial synchronism.

1.5.3 ***Camera Synchronism.*** Camera synchronism is the relationship between picture and sound on an original composite negative.

NOTE: Camera synchronism is generally not the same as projection synchronism and is never the same as editorial synchronism. The relationship between picture and sound may vary among different type cameras.

1.6 Exposure. Exposure is the process of subjecting a photographic film to any given intensity of light in such a manner that it may produce a latent image on the emulsion.

1.7 Development. Development is the process of treating an exposed photographic emulsion to make the latent image visible.

NOTE: This term is sometimes incorrectly used in the trade to include both fixation and washing of the developed image and drying of the film. The correct term for these operations as a group is processing.

1.7.1 ***Fixing (Fixation).*** Fixing (fixation) is the process of removing the residual sensitive silver halides from a developed film to render the developed image permanent.

NOTE: During the process of fixation, films are customarily treated to preserve and harden the developed image.

1.8 Printing. Printing is the process of exposing raw stock by using the image of another film as the light modulator.

NOTE: Through printing, one may produce a positive print from a negative film; a negative film from a positive film; or, if the reversal process is employed, printing may be used to produce positives from positives or negatives from negatives. When the verb "to print" is used, any of the above processes may be implied.

1.8.1 ***Contact Printing.*** Contact printing is that method of printing in which the raw stock is held in intimate contact with the film bearing the image to be copied.

1.8.2 ***Projection Printing (Optical Printing).*** Projection printing (optical printing) is

printing by projecting the image to be copied on the raw stock.

NOTE: When projection printing, the image being copied may be enlarged, reduced, or made the same size.

1.8.2.1 *Reduction Printing.* Reduction printing is the process of producing and recording photographically a smaller image, usually on a smaller film, from a larger image.

NOTE: This process is commonly used in making 16-mm negatives or prints from 35-mm originals. Film thus made is referred to as a reduction negative or reduction print, as the case may be.

1.9 Projection. Projection is the process of presenting a film for either visual or aural review, or both.

1.10 Production. Production is the general term used to describe the processes involved in making all the original material that is the basis for the finished motion picture.

1.11 Editorial Process. Editorial process is the term used to describe the combining, cutting, editing, and other preparation of material obtained from the original material to make the finished motion picture.

1.12 Re-recording. Re-recording is the electrical process of transferring sound records from one or more films or discs to other films or discs.

NOTE: Re-recording may be used to combine different sound records into a single record; to adjust the response-frequency characteristic; or to adjust the relative levels between different scenes and sequences.

1.13 Release. Release is a generic term used to designate films used for or intended for general distribution and exhibition.

NOTE: Unless specifically stated, release refers only to the normal or domestic release of 35-mm motion picture production through agencies within the United States.

1.13.1 ***16-Mm Release.*** A 16-mm release designates any or all the releases made on 16-mm film.

1.13.2 ***Foreign Release.*** A foreign release is any release made to agencies outside the United States.

NOTE: A descriptive adjective is usually applied to name the specific country or territory to which the release will go. As an example, a release made to Spain would be termed a Spanish release.

1.13.2.1 *16-Mm Foreign Release.* A 16-mm foreign release is a foreign release made on 16-mm film.

NOTE: As an example, a release made to Spain on 16-mm film would be termed a 16-mm Spanish release.

1.13.3 ***Release Negative.*** A release negative is a complete negative prepared specifically for printing release prints.

NOTE: A release negative may consist of separate picture and sound negatives and may be in either projection or editorial synchronism, depending upon the film processing technique to be employed in making release prints.

1.14 35-Mm Negative Blow-up. A 35-mm negative blow-up is a negative made by the optical printing process in which a larger negative image is produced from a smaller positive image.

NOTE: 35-mm negative blow-ups may be made from a 16-mm or possibly an 8-mm positive by the use of the optical printing process.

1.15 Matte Rolls (Traveling Masks). Matte rolls (traveling masks) are a pair of film rolls used as light modulators.

NOTE: Matte rolls are complementary in that where one roll is clear, the other is effectively opaque. They are usually matched to rolls of original black and white, or of color reversal positives in the printing of black and white or color duplicates.

2. Negative Film

2.1 Negative. The term "negative" is used to designate any of the following:

(*a*) the raw stock specifically designed for negative images

(*b*) the negative image

(*c*) negative raw stock which has been exposed but has not been processed

(*d*) film bearing a negative image which has been processed.

2.2 Picture Negative. A picture negative is any negative film which, after exposure to a subject or positive image and subsequent processing, produces a negative picture image on the film.

2.2.1 ***Original Picture Negative.*** The original picture negative is the negative film which is exposed in the camera and subsequently processed to produce an original negative picture image.

2.2.2 ***Background Plate Negative.*** A background plate negative is a picture negative which is used to print background plates.

2.2.3 ***Picture Library Negative.*** A picture library negative is a picture negative which is usually held in a stock library for use in reproducing scenes which would otherwise have to be made as original material for each production.

2.2.4 ***Title Negative.*** A title negative is a picture negative which is exposed to a title card or to both a title card and background.

2.2.5 ***Picture Dupe Negative.*** A picture dupe negative is a picture negative made from a picture duping print.

NOTE: It may be used for making other picture prints or may be cut to form a part of the picture release negative.

2.2.6 ***Picture Release Negative.*** A picture release negative is a release negative used for printing the picture portion of release prints.

NOTE: It may consist of intercut original picture negatives, picture dupe negatives, etc, depending upon the choice of available material or the intended use of the release print.

2.2.7 ***Foreign Picture Release Negative.*** A foreign picture release negative is a picture release negative prepared specifically for printing foreign version release prints.

NOTE: It is almost invariably a dupe negative.

2.2.8 ***16-Mm Picture Release Negative.*** A 16-mm picture release negative is a picture release negative on 16-mm film prepared specifically for printing 16-mm release prints.

NOTE: It is generally a dupe negative.

2.2.9 ***Picture Release Dupe Negative.*** A picture release dupe negative is a picture dupe negative prepared specifically for printing the picture portion of release prints.

2.3 Sound Negative. A sound negative is any negative film which, after exposure to a positive sound image and subsequent processing, produces a negative sound track on the film.

2.3.1 ***Original Sound Negative.*** The original sound negative is the sound negative which is exposed in a film recorder and after processing produces a negative sound image on the film.

2.3.2 ***Sound Effects Negative.*** A sound effects negative is a sound negative upon which sound effects have been recorded.

NOTE: It is ordinarily held in library stock.

2.3.3 ***Music Negative.*** A music negative is a sound negative upon which music has been recorded.

NOTE: It is usually an original sound negative but may be a library negative.

2.3.4 ***Sound Cut Negative.*** A sound cut negative is a sound negative which is intercut from an original sound negative.

NOTE: It is generally in exact conformity with the sound work print, and produces a single combined negative. The print of the sound cut negative provides all, or portions of, the re-recording print.

2.3.5 ***Re-recorded Negative.*** A re-recorded negative is a sound negative which is exposed by re-recording and when processed produces a negative sound-track image.

2.3.6 ***Sound Release Negative.*** A sound release negative is a release negative prepared for printing the sound portion of release prints.

NOTE: It may consist of re-recorded negatives, intercut original sound negatives, sound dupe negatives, etc, depending upon the choice of available material or the intended use of the print.

2.3.6.1 *Special Sound Release Negative.* A special sound release negative is a sound release negative made for the purpose of obtaining a sound track which has characteristics other than the sound release negative.

NOTE: It may be a sound track for use in foreign version release, foreign English language version release, or 16-mm release from 35-mm original material. It usually has undergone an additional re-recording operation.

2.3.6.1a *Special Sound Release Negative for Use in 16-Mm Release of 35-Mm Preprint Material.* The special sound release negative for 16-mm release of 35-mm original material is usually re-recorded.

NOTE: It may be re-recorded from a print of the 35-mm sound release negative or from the 35-mm re-recording print.

2.3.6.1b *Special Sound Release Negative Used in English Version for Foreign Release.* The special sound release negative for use in English version for foreign release is re-recorded from the re-recording print, except that the dialogue track is modified to remove American colloquialism.

2.3.6.1c *Special Sound Release Negative Used in Foreign Language Version.* The special sound release negative for use in foreign language version release is usually re-recorded using all of re-recording tracks, except the dialogue track for which is substituted a special synchronized dialogue track in the foreign language for which the release is being made.

2.3.7 ***Sound Release Dupe Negative.*** A sound release dupe negative is a sound dupe negative prepared specifically for printing the sound track of release prints.

2.4 Composite Negative. A composite negative is a negative film which is exposed and processed to produce both sound track and picture negative images on the same film.

NOTE: The sound and picture may be in editorial, projection or camera synchronism, depending upon the manner in which the composite negative is made and its intended use.

2.4.1 *Composite Original Negative.* A composite original negative is a composite negative which, after exposure and processing, produces an original negative picture and sound track image in camera synchronism.

2.4.2 *Composite Dupe Negative.* A composite dupe negative is a composite negative which, after exposure and processing, produces a dupe negative picture and sound track image.

NOTE: It is usually used for printing foreign version release prints and is frequently in editorial synchronism.

3. Positive Film

3.1 Print or Positive. The term "positive" or "print" is used to designate any of the following:

(*a*) the raw stock specifically designed for positive images

(*b*) the positive image

(*c*) positive raw stock which has been exposed but has not been processed

(*d*) film bearing a positive image which has been processed.

3.2 Picture Print. A picture print is any positive printed from a picture negative.

3.2.1 *Picture Daily Print.* A picture daily print is the first picture print made from the original picture negative for use in checking photographic quality, camera technique, action, etc.

3.2.2 *Picture Work Print.* A picture work print is a positive print which usually consists of intercut picture daily prints, picture library prints, prints of dissolves, montages, titles, etc, and has synchronism constantly maintained with the corresponding sound work print.

NOTE: A picture work print is used to edit and combine the various picture scenes of a motion picture into the desired form.

3.2.3 *Picture Library Print.* A picture library print is a picture print made from a picture library negative.

3.2.4 *Background Plate (Background Film).* A background plate (background film) is a picture print made specifically for use in projection backgrounds or similar process work, and is a print of a background plate negative.

NOTE: Background plates are usually made on special stock having negative perforations.

3.2.5 *Picture Duping Print.* A picture duping print is a picture print made on a special film for the purpose of producing a duplicate negative or for producing dissolves, montages, titles, etc.

NOTE: Duping print is synonymous with master positive except that duping print is the term used in the editorial process, while master positive is used in release.

3.2.5.1 *Picture Master Positive.* A picture master positive is a picture duping print usually made for the purpose of producing a picture dupe negative for release printing.

3.2.6 *Print from Picture Dupe Negative.* A print from a picture dupe negative is any print made from a picture dupe negative, and is usually a projection print used for editorial purposes.

3.2.7 *Picture Check Print.* A picture check print is a picture print made from the picture release negative for the purpose of checking negative cutting, printing lights, picture quality, etc.

NOTE: When a picture check print is required, it is usually made prior to the first trial composite print.

3.3 Sound Print. A sound print is any positive printed from a sound negative.

3.3.1 *Sound Daily Print.* A sound daily print is the first sound print made from the original sound negative for checking sound quality, technique, etc.

3.3.2 *Sound Work Print.* A sound work print is a sound print which usually consists of intercut sound daily prints, but may also include other sound tracks of sound effects or music, or both, on the same or separate films with synchronism constantly maintained with the corresponding picture work print.

3.3.3 *Sound Effects Print.* A sound effects print is a sound print made from a sound effects negative.

3.3.4 ***Music Print.*** A music print is a sound print made from a music negative.

3.3.5 ***Re-recording Print.*** A re-recording print is a sound print prepared specifically for use in re-recording to produce a re-recorded negative.

NOTE: It may be a print from a sound cut negative, a specially intercut print, or a combination of both. A re-recording print may consist of several sound records on separate films including dialogue, sound effects, music or any other required material. The term is used interchangeably to designate the entire group of associated films or any individual film which is part of the group.

3.3.6 ***Re-recorded Print.*** A re-recorded print is a sound print from a re-recorded sound track negative.

3.3.7 ***Sound Check Print.*** A sound check print is a sound print made from the sound release negative for the purpose of checking negative cutting, printing lights, sound quality, etc.

NOTE: When a sound check print is required, it is usually made prior to the first trial composite print.

3.3.8 ***Sound Master Positive.*** A sound master positive is a sound print on special film stock and is usually made from a sound release negative for the purpose of producing sound dupe negatives for release printing.

3.4 Composite Print. A composite print is a positive film having both picture and sound track images on the same film which may be in editorial or projection synchronism.

3.4.1 ***Composite Daily Print.*** A composite daily print is the first print made from an original composite negative or an original sound and picture negative, and is used for checking photography, sound quality, action, etc. It is in projection synchronism.

3.4.2 ***First Trial Composite Print.*** The first trial composite is the first composite print made from the picture and sound release negatives for the purpose of checking and correcting picture and sound quality, negative cutting and assembly, etc. It is in projection synchronism.

3.4.3 ***Second, Third, etc, Trial Composite Print.*** The second, third, etc, trial composite print is similar to the first trial composite print but has successive corrections incorporated as a result of viewing the previous trial composite prints.

3.4.4 ***Final Trial Composite (Sample Print).*** A final trial composite (sample print) is a composite print, approved for release, in which all corrections found necessary in previous trial composite prints have been incorporated.

NOTE: The final trial composite may be any one of the various trial composite prints, depending upon the type and extent of corrections required.

3.4.5 ***Composite Master Positive.*** A composite master positive is a composite print usually made for the purpose of producing composite or picture and sound dupe negatives which would be used for printing release prints.

NOTE: It is usually made on duplicating raw stock and may be in either editorial or projection synchronism.

3.4.6 ***Release Print.*** A release print is a composite print made for general distribution and exhibition after the final trial composite or sample print has been approved. It is in projection synchronism.

3.4.6.1 *Foreign Version Release Prints.* Foreign version release prints are composite prints in projection synchronism and are made specifically for the particular version involved.

3.4.7 ***Foreign Version Trial Composite Prints.*** Foreign version trial composite prints are similar to trial composite prints made during release except that they are made for checking the release of the particular version involved.

4. Color and Reversal Film Terms

4.1 Reversal Film. A reversal film is one which after exposure is processed to produce a positive image on the same film rather than the customary negative image. If exposure is made by printing from a negative, a negative image is produced directly.

NOTE: Reversal films may be black and white, or color, and either sound or picture or both, and they are usually 16-mm films.

4.2 Reversal Process. The reversal process is the photographic process which reversal films undergo. It is a process in which a latent image is developed to a silver image by primary development, destroyed by a chemical bleach, and the remaining sensitized material exposed and developed in a second developer bath before fixing and washing.

4.3 Reversal Original. A reversal original is the film which is originally exposed in a camera or recorder and is processed by reversal to produce a positive image.

NOTE: This positive image is not the same as a print from a negative inasmuch as right and left are transposed. A reversal original may be a black and white, or color, film.

4.3.1 ***Composite Reversal Original.*** A composite reversal original is a reversal original which has both picture and sound on the same film.

4.3.2 ***Original Color Positive.*** An original color positive is a color reversal original which is developed by the reversal process to produce a positive color image.

4.3.3 ***Composite Original Color Positive.*** A composite original color positive is an original color positive with sound track and picture on the same film.

4.4 Dupe Negative from Original Reversal, 16-Mm. A dupe negative from an original reversal is a negative made from an original reversal positive or an original color positive. The image on such a dupe negative is not transposed right to left. It is usually used to make black and white prints.

4.5 Reversal Print. A reversal print is a print which is made on reversal film and developed by the reversal process.

NOTE: A reversal print is usually a positive.

4.5.1 ***Reversal Dupe Print, 16-Mm.*** A reversal dupe print is a reversal print which is printed from a black and white, or color, reversal original and processed by reversal to obtain a positive black and white image.

4.5.2 ***Color Dupe Print.*** A color dupe print is a color reversal which is printed from a color reversal original and processed to obtain a positive color image.

4.5.3 ***Composite Color Dupe Print.*** A composite color dupe print is a print made from an original composite color positive or from an original picture color positive and a sound track, and is processed to obtain a positive color print of both picture and sound track.

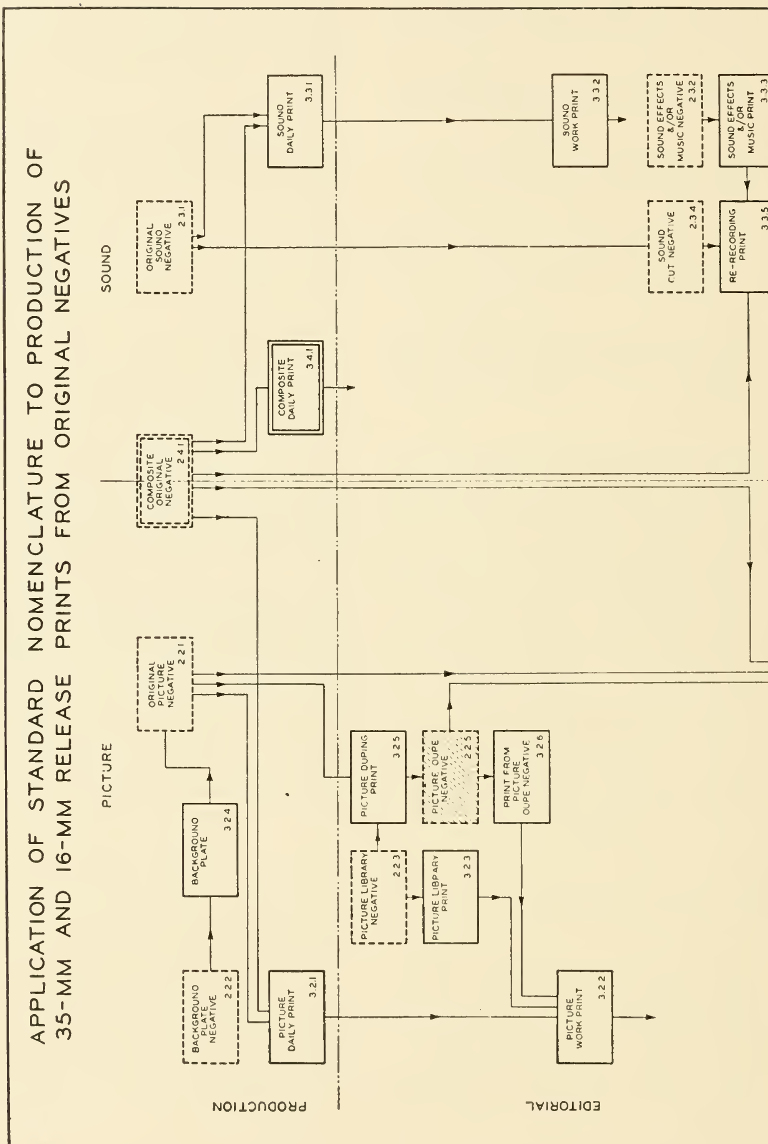
4.5.4 ***Composite Reversal Dupe Print, 16-Mm.*** A composite reversal dupe print is a reversal dupe print having both picture and sound tracks on the same film.

4.5.5 ***Reduction Reversal Print, 16-Mm.*** A reduction reversal print is a reversal print made on 16-mm reversal film from a 35-mm positive by reduction printing and development by the reversal process.

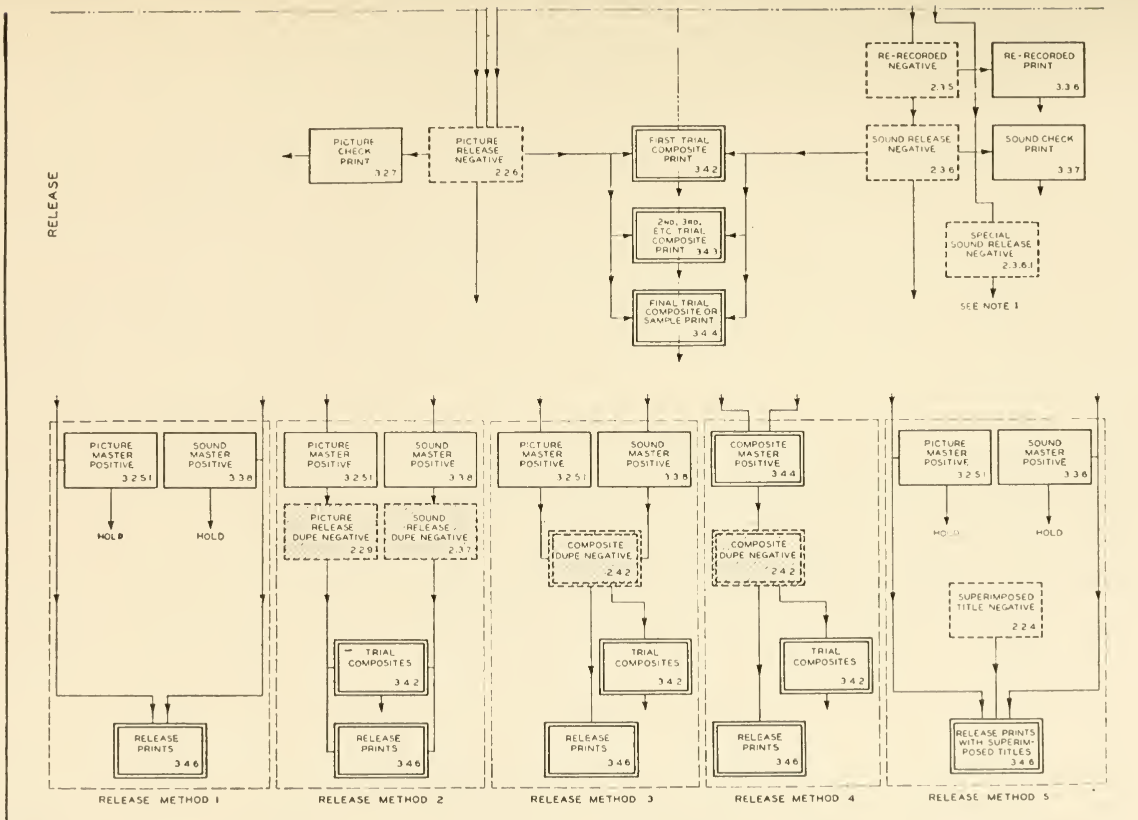
4.5.6 ***Reversal Master Print, 16-Mm.*** A reversal master print is a 16-mm reversal print made specifically for use in producing other prints.

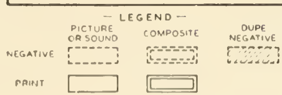
NOTE: It is sometimes referred to as a first generation dupe, prints from it then being referred to as second generation dupes.

NOTE: A process diagram showing the relationships of terms is on pages 554 and 555.



APPLICATION OF STANDARD NOMENCLATURE TO PRODUCTION OF
35-MM AND 16-MM RELEASE PRINTS FROM ORIGINAL NEGATIVES
PICTURE
SOUND
PRODUCTION
EDITORIAL
BACKGROUND PLATE NEGATIVE 2.2.2
BACKGROUND PLATE 3.2.4
ORIGINAL PICTURE NEGATIVE 2.2.1
PICTURE DAILY PRINT 3.2.1
COMPOSITE ORIGINAL NEGATIVE 2.4.1
COMPOSITE DAILY PRINT 3.4.1
ORIGINAL SOUND NEGATIVE 2.3.1
SOUND DAILY PRINT 3.3.1
PICTURE LIBRARY NEGATIVE 2.2.3
PICTURE LIBRARY PRINT 3.2.3
PICTURE DUPING PRINT 3.2.5
PICTURE DUPE NEGATIVE 2.2.5
PRINT FROM PICTURE DUPE NEGATIVE 3.2.6
PICTURE WORK PRINT 3.2.2
SOUND WORK PRINT 3.3.2
SOUND CUT NEGATIVE 2.3.4
SOUND EFFECTS &/OR MUSIC NEGATIVE 2.3.2
SOUND EFFECTS &/OR MUSIC PRINT 3.3.3
RE-RECORDING PRINT 3.3.5





NOTE 1. The SPECIAL SOUND RELEASE NEGATIVE is substituted for the SOUND RELEASE NEGATIVE when making special version release prints, such as FOREIGN VERSION RELEASE, 16-MM RELEASE, etc.

NOTE 2. In release method 1, a PICTURE MASTER POSITIVE and a SOUND MASTER POSITIVE are always made prior to release printing.

NOTE 3. In release methods 2, 3, and 4, dupe negatives may be either reduction dupes or a dupe from a 16-mm negative, if release is to be made on 16-mm film. When a limited number of 16-mm prints are to be made, 16-MM RELEASE PRINTS are sometimes made directly from the 35-mm negative by optical reduction printing.

NOTE 4. In release method 5, RELEASE PRINTS (with superimposed titles) are usually made when all other release print work has been completed.

INDEX OF ASA STANDARDS REVISED AS OF FEBRUARY, 1953

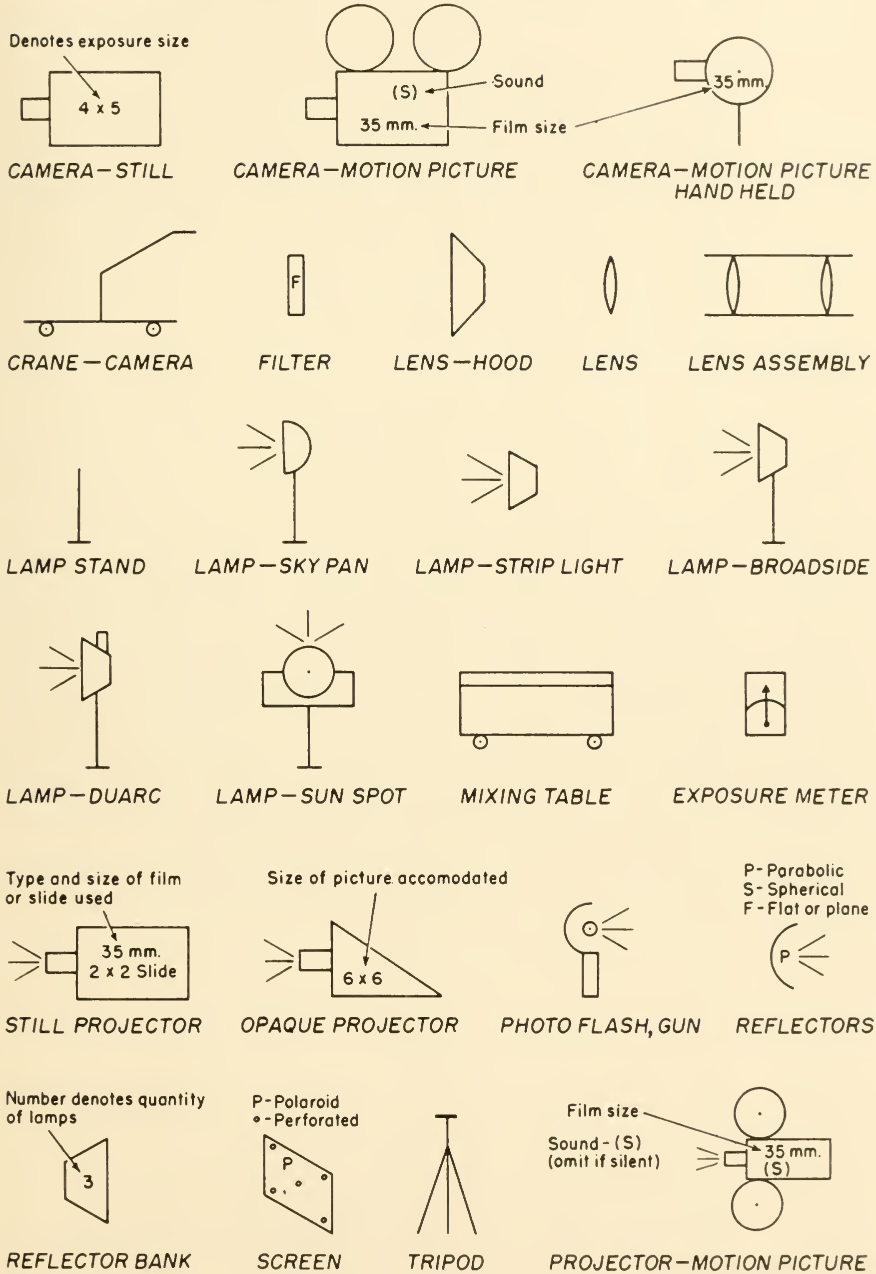
PH22.1 — 1953[a]
Z22.2 — 1946[b]
Z22.3 — 1946[b]
Z22.4 — 1941[b]
PH22.5 (Z22.5)[b]
Z22.6 — 1950[c]
Z22.8 — 1950[a]
Z22.9 — 1946[a]
Z22.10 — 1947[b]
PH22.11 — 1952[b]
PH22.12 (Z22.12)[b]
Z22.13 — 1941[c]
Z22.14 — 1941[c]
PH22.15[b]
PH22.16[b]
Z22.17 — 1947[b]
Z22.18 — 1941[c]
Z22.19 — 1950[a]
Z22.20 — 1950[a]
Z22.21 — 1946[b]
Z22.22 — 1947[b]
Z22.23 — 1941[b]
PH22.24 — 1952[a]
(Z22.24 and Z22.25)
Z22.25 — 1941[c]
Z22.26 — 1941[c]
Z22.27 — 1947[a]
Z22.28 — 1946[b]
Z22.29 — 1948[a]
Z22.30 — 1941[c]
Z22.31 — 1946[b]
Z22.32 — 1941[c]
Z22.33 — 1941[c]
Z22.34 — 1944[a]
Z22.35 — 1947[b]
Z22.36 — 1947[a]
Z22.37 — 1944[a]
PH22.38 (Z22.38)[a]
PH22.39[b]
Z22.40 — 1950[a]
Z22.41 — 1946[b]
Z22.42 — 1946[b]
Z22.43 — 1946[a]
Z22.44 — 1946[a]
Z22.45 — 1946[b]
Z22.46 — 1946[a]
Z22.47 — 1946[a]
Z22.48 — 1946[b]
Z22.49 — 1946[b]
PH22.50 — 1952[a]
Z22.51 — 1946[a]
Z22.52 — 1946[a]
Z22.53 — 1946[b]
Z22.54 — 1946[b]
Z22.55 — 1947[b]
Z22.56 — 1947[b]
Z22.57 — 1947[b]
Z22.58 — 1947[b]
Z22.59 — 1947[b]
Z22.60 — 1948[a]
Z22.61 — 1949[a]
Z22.62 — 1948[a]
Z22.63[c]
Z22.64[c]
Z22.65 — 1948[a]
Z22.66 — 1948[a]
Z22.67 — 1948[a]
Z22.68 — 1949[a]
Z22.69 — 1948[a]
Z22.70 — 1948[a]
PH22.71 — 1950
(Z22.71 — 1950)[a]
PH22.72 — 1950
(Z22.72 — 1950)[a]
PH22.73 — 1951[a]
PH22.74 — 1951[a]
PH22.75[b]

[a]American Standard in force. [b]American Standard in process of revision. [c]Withdrawn. [d]Proposed American Standard.

Abstracted from "Index to Standards and Recommendations," February, 1953. The titles of the standards will be found in this index.

APPENDIX B

SYMBOLS PROPOSED FOR MOTION PICTURE EQUIPMENT



APPENDIX C

PERCENT TRANSMISSION *vs.* PHOTOGRAPHIC DENSITY

Transmission, %	Density									
	0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0		3.00	2.70	2.52	2.40	2.30	2.22	2.15	2.10	2.05
1	2.00	1.96	1.92	1.89	1.85	1.82	1.80	1.77	1.74	1.72
2	1.70	1.68	1.66	1.64	1.62	1.60	1.59	1.57	1.55	1.54
3	1.52	1.51	1.50	1.48	1.47	1.46	1.44	1.43	1.42	1.41
4	1.40	1.39	1.38	1.37	1.36	1.35	1.34	1.33	1.32	1.31
5	1.30	1.29	1.28	1.28	1.27	1.26	1.25	1.24	1.24	1.23
6	1.22	1.21	1.21	1.20	1.19	1.19	1.18	1.17	1.17	1.16
7	1.15	1.15	1.14	1.14	1.13	1.13	1.12	1.11	1.11	1.10
8	1.10	1.09	1.09	1.08	1.08	1.07	1.07	1.06	1.06	1.05
9	1.05	1.04	1.04	1.03	1.03	1.02	1.02	1.01	1.01	1.00
10	1.00	1.00	0.99	0.99	0.98	0.98	0.97	0.97	0.97	0.96
11	0.96	0.95	0.95	0.95	0.94	0.94	0.93	0.93	0.93	0.92
12	.92	.92	.91	.91	.91	.90	.90	.90	.89	.89
13	.89	.88	.88	.88	.87	.87	.87	.86	.86	.86
14	.85	.85	.85	.84	.84	.84	.84	.83	.83	.83
15	.82	.82	.82	.82	.81	.81	.81	.80	.80	.80
16	.80	.79	.79	.79	.78	.78	.78	.78	.77	.77
17	.77	.77	.76	.76	.76	.76	.75	.75	.75	.75
18	.74	.74	.74	.74	.73	.73	.73	.73	.73	.72
19	.72	.72	.72	.71	.71	.71	.71	.71	.70	.70
20	.70	.70	.69	.69	.69	.69	.69	.68	.68	.68
21	.68	.68	.67	.67	.67	.67	.67	.66	.66	.66
22	.66	.66	.65	.65	.65	.65	.65	.64	.64	.64
23	.64	.64	.63	.63	.63	.63	.63	.63	.62	.62
24	.62	.62	.62	.61	.61	.61	.61	.61	.60	.60
25	.60	.60	.60	.60	.59	.59	.59	.59	.59	.59
26	.58	.58	.58	.58	.58	.58	.57	.57	.57	.57
27	.57	.57	.57	.57	.56	.56	.56	.56	.56	.56
28	.55	.55	.55	.55	.55	.54	.54	.54	.54	.54
29	.54	.54	.53	.53	.53	.53	.53	.53	.53	.52
30	.52	.52	.52	.52	.52	.52	.51	.51	.51	.51
31	.51	.51	.51	.50	.50	.50	.50	.50	.50	.50
32	.49	.49	.49	.49	.49	.49	.49	.49	.48	.48
33	.48	.48	.48	.48	.48	.47	.47	.47	.47	.47
34	.47	.47	.47	.46	.46	.46	.46	.46	.46	.46
35	.46	.45	.45	.45	.45	.45	.45	.45	.45	.44
36	.44	.44	.44	.44	.44	.44	.44	.44	.43	.43
37	.43	.43	.43	.43	.43	.43	.42	.42	.42	.42
38	.42	.42	.42	.42	.42	.41	.41	.41	.41	.41
39	.41	.41	.41	.41	.40	.40	.40	.40	.40	.40
40	.40	.40	.40	.40	.39	.39	.39	.39	.39	.39
41	.39	.39	.39	.38	.38	.38	.38	.38	.38	.38
42	.38	.38	.38	.37	.37	.37	.37	.37	.37	.37
43	.37	.37	.37	.36	.36	.36	.36	.36	.36	.36
44	.36	.36	.35	.35	.35	.35	.35	.35	.35	.35
45	.35	.35	.34	.34	.34	.34	.34	.34	.34	.34
46	.34	.34	.33	.33	.33	.33	.33	.33	.33	.33
47	.33	.33	.33	.32	.32	.32	.32	.32	.32	.32
48	.32	.32	.32	.32	.32	.31	.31	.31	.31	.31
49	.31	.31	.31	.31	.31	.31	.30	.30	.30	.30
50	.30	.30	.30	.30	.30	.30	.29	.29	.29	.29
	0	.1	.2	.3	.4	.5	.6	.7	.8	.9

APPENDIX C

Transmission, %	Density									
	0	.1	.2	.3	.4	.5	.6	.7	.8	.9
51	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.28
52	.28	.28	.28	.28	.28	.28	.28	.28	.28	.28
53	.28	.28	.27	.27	.27	.27	.27	.27	.27	.27
54	.27	.27	.27	.27	.26	.26	.26	.26	.26	.26
55	.26	.26	.26	.26	.26	.25	.25	.25	.25	.25
56	.25	.25	.25	.25	.25	.25	.25	.25	.25	.24
57	.24	.24	.24	.24	.24	.24	.24	.24	.24	.24
58	.24	.24	.24	.23	.23	.23	.23	.23	.23	.23
59	.23	.23	.23	.23	.23	.23	.22	.22	.22	.22
60	.22	.22	.22	.22	.22	.22	.22	.22	.22	.22
61	.21	.21	.21	.21	.21	.21	.21	.21	.21	.21
62	.21	.21	.21	.21	.20	.20	.20	.20	.20	.20
63	.20	.20	.20	.20	.20	.20	.20	.20	.19	.19
64	.19	.19	.19	.19	.19	.19	.19	.19	.19	.19
65	.19	.19	.19	.19	.18	.18	.18	.18	.18	.18
66	.18	.18	.18	.18	.18	.18	.18	.18	.17	.17
67	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17
68	.17	.17	.17	.17	.16	.16	.16	.16	.16	.16
69	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16
70	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15
71	.15	.15	.15	.15	.15	.15	.14	.14	.14	.14
72	.14	.14	.14	.14	.14	.14	.14	.14	.14	.14
73	.14	.14	.14	.13	.13	.13	.13	.13	.13	.13
74	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13
75	.12	.12	.12	.12	.12	.12	.12	.12	.12	.12
76	.12	.12	.12	.12	.12	.12	.12	.11	.11	.11
77	.11	.11	.11	.11	.11	.11	.11	.11	.11	.11
78	.11	.11	.11	.11	.11	.10	.10	.10	.10	.10
79	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10
80	.10	.10	.10	.10	.09	.09	.09	.09	.09	.09
81	.09	.09	.09	.09	.09	.09	.09	.09	.09	.09
82	.09	.09	.08	.08	.08	.08	.08	.08	.08	.08
83	.08	.08	.08	.08	.08	.08	.08	.08	.08	.08
84	.08	.07	.07	.07	.07	.07	.07	.07	.07	.07
85	.07	.07	.07	.07	.07	.07	.07	.07	.07	.07
86	.07	.06	.06	.06	.06	.06	.06	.06	.06	.06
87	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06
88	.06	.05	.05	.05	.05	.05	.05	.05	.05	.05
89	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05
90	.05	.04	.04	.04	.04	.04	.04	.04	.04	.04
91	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04
92	.04	.04	.04	.03	.03	.03	.03	.03	.03	.03
93	.03	.03	.03	.03	.03	.03	.03	.03	.03	.03
94	.03	.03	.03	.03	.02	.02	.02	.02	.02	.02
95	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02
96	.02	.02	.02	.02	.02	.02	.01	.01	.01	.01
97	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
98	.01	.01	.01	.01	.01	.01	.01	.01	.01	.00
99	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
100	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
	0	.1	.2	.3	.4	.5	.6	.7	.8	.9

[a] $D = \log_{10} 1/\text{Transmission}$.

APPENDIX D

COMPARISON OF EMULSION-SPEED VALUES[a]

ASA film numbers	Weston	General electric	H & D	American scheiner	European scheiner	Din
—	0.3	—	7.5	4	10	—
—	0.35	—	8.75	5	11	—
0.6	0.5	—	12.5	6	12	—
0.8	0.6	—	15	7	13	—
1.0	0.7	1	17.5	8	14	1/10
1.2	1.0	1.5	25	9	15	2/10
1.6	1.2	2	30	10	16	3/10
2.0	1.5	—	38	11	17	4/10
2.5	2.0	3	50	12	18	5/10
3	2.5	4	63	13	19	6/10
4	3	4.5	75	14	20	7/10
5	4	—	100	15	21	8/10
6	5	7.5	125	16	22	9/10
8	6	9	150	17	23	10/10
10	8	12	200	18	24	11/10
12	10	15	250	19	25	12/10
16	12	18	300	20	26	13/10
20	16	24	400	21	27	14/10
25	20	30	500	22	28	15/10
32	24	36	600	23	29	16/10
40	32	48	800	24	30	17/10
50	40	60	1,000	25	31	18/10
64	50	75	1,250	26	32	19/10
80	64	100	1,600	27	33	20/10
100	80	120	2,000	28	34	21/10
125	100	150	2,500	29	35	22/10
160	125	200	3,120	30	36	23/10
200	160	250	4,000	31	37	24/10
250	200	300	5,000	32	38	25/10
320	250	400	6,250	33	39	26/10
400	320	500	8,000	34	40	27/10
500	400	600	10,000	35	41	28/10
650	500	800	12,500	36	42	29/10
800	650	900	16,250	37	43	30/10
1000	800	1,000	20,000	38	44	31/10

[a] The table is only a rough guide to comparative speed values, since it is impossible to convert one kind of speed rating into another. (The different rating systems are based upon entirely different premises, methods, and test conditions.) The ASA rating is a manufacturer's test made at the time of manufacture; by definition it does not cover motion picture or color films. The Weston rating specifies purchase on the open market and 3 months' storage at $20 \pm 5°$ C. and 55 ± 5 percent relative humidity prior to processing.

APPENDIX E

DECIBELS GAIN OR LOSS *vs.* VOLTAGE AND CURRENT RATIO AND POWER RATIO[a]

Decibels[b]	Power ratio[b]	Voltage and current ratio[b]	Decibels	Power ratio	Voltage and current ratio
0.1	1.0233	1.0116	13.0	19.953	4.4668
0.2	1.0471	1.0233	14.0	25.119	5.0119
0.3	1.0715	1.0351	15.0	31.623	5.6234
0.4	1.0965	1.0471	16.0	39.811	6.3096
0.5	1.1220	1.0593	17.0	50.119	7.0795
0.6	1.1482	1.0715	18.0	63.096	7.9433
0.7	1.1749	1.0839	19.0	79.433	8.9125
0.8	1.2023	1.0965	20.0	100.00	10.0000
0.9	1.2303	1.1092	22.0	158.49	12.589
1.0	1.2589	1.1220	24.0	251.19	15.849
1.2	1.3183	1.1482	26.0	398.11	19.953
1.4	1.3804	1.1749	28.0	630.96	25.119
1.6	1.4454	1.2023	30.0	1000.0	31.623
1.8	1.5136	1.2303	32.0	1584.9	39.811
2.0	1.5849	1.2589	34.0	2511.9	50.119
2.2	1.6595	1.2882	36.0	3981.1	63.096
2.4	1.7378	1.3183	38.0	6309.6	79.433
2.6	1.8197	1.3490	40.0	10^4	100.000
2.8	1.9055	1.3804	42.0	$10^4 \times 1.5849$	125.89
3.0	1.9953	1.4125	44.0	$10^4 \times 2.5119$	158.49
3.5	2.2387	1.4962	46.0	$10^4 \times 3.9811$	199.53
4.0	2.5119	1.5849	48.0	$10^4 \times 6.3096$	251.19
4.5	2.8184	1.6788	50.0	10^5	316.23
5.0	3.1623	1.7783	52.0	$10^5 \times 1.5849$	398.11
5.5	3.5481	1.8836	54.0	$10^5 \times 2.5119$	501.19
6.0	3.9811	1.9953	56.0	$10^5 \times 3.9811$	630.96
7.0	5.0119	2.2387	58.0	$10^5 \times 6.3096$	794.33
8.0	6.3096	2.5119	60.0	10^6	1,000.00
9.0	7.9433	2.8184	70.0	10^7	3,162.3
10.0	10.0000	3.1623	80.0	10^8	10,000.0
11.0	12.589	3.5481	90.0	10^9	31,623
12.0	15.849	3.9811	100.0	10^{10}	100,000

[a] To convert

Decibels to nepers multiply by 0.1151

Nepers to decibels multiply by 8.686

Where the power ratio is less than unity, invert the fraction and express the result as a decibel loss.

[b] $\mathrm{Db} = 20 \times \log_{10} \frac{V_1}{V_2} = 20 \log_{10} \frac{I_1}{I_2} = 10 \log_{10} \frac{P_1}{P_2}$

APPENDIX F

ASA STANDARDS VS. GOVERNMENT SPECIFICATIONS

The ASA Sectional Committee for Motion Pictures, Z22, has been in existence since 1932. Its function is to coordinate the standardization work of manufacturers, trade associations, engineering and professional societies, and other interested and active parties, such as the representatives of government. Z22 is sponsored by the Society of Motion Picture Engineers; such sponsorship assures that a project suggested for standardization will receive thorough study and consideration by specialists in the field of motion pictures, especially since most projects are brought to the attention of Z22 through the SMPE.

During World War II, the United States Armed Forces requested standardization efforts of ASA and the SMPE in preparing performance specifications for motion picture equipment, accessories, and processes. This activity resulted in two groups of motion picture standards, one of permanent interest that was referred to Z22, and another of interest only for the duration of the war that was referred to a War Committee, Z52. Some Z52 standards were modified and approved through Z22 at the end of the War, others were dropped. A number of the standards that were dropped are still of interest to the government; accordingly they have been studied by government technical committees and adopted (usually with modifications) as government specifications. The table following describes comparable specifications, and the status of such government specifications as of mid-1949.

American Standards

American Standards Association, Inc., 70 East 45 Street, New York, 17, N. Y., issues without charge a price list of *American Standards.* A set of current motion picture standards can be obtained from the Society of Motion Picture Engineers at 342 Madison Ave., New York, 17, N. Y. The SMPE also offers a service of keeping a *Standards* subscriber up-to-date by sending each new motion picture standard as it is approved. Inquiries should be addressed to the secretaries of the respective organizations.

ASA standard	Applicable government specification	Specification status
Z22.2—1946	None	—
Z22.3—1946	"	—
Z22.4—1941	USA 75-189	Under revision
Z22.5—1941	JAN-S-424	Approved
Z22.6—1941	JAN-S-424	"
Z22.7—1941	JAN-S-424	"
Z22.8—1941	JAN-S-424	"
Z22.9—1946	JAN-S-424	"
Z22.10—1941	JAN-S-424	"
Z22.11—1941	JAN-R-214	"
Z22.12—1941	JAN-S-424	"
Z22.13—1941	JAN-S-424	"
Z22.14—1941	JAN-S-424	"
Z22.15—1946	JAN-S-424	"

ASA standard	Applicable government specification	Specification status
Z22.16—1941	JAN-S-424	"
Z22.17—1941	None	—
Z22.18—1941	"	—
Z22.19—1941	"	—
Z22.20—1941	"	—
Z22.21—1946	"	—
Z22.22—1941	"	—
Z22.23—1941	"	—
Z22.24—1941	JAN-S-424	Approved
Z22.25—1941	JAN-S-424	"
Z22.26—1941	None	—
Z22.27—1941	"	—
Z22.28—1946	"	—
Z22.29—1946	JAN-S-258	In press
" "	JAN-S-259	"
" "	JAN-S-260	"
" "	JAN-S-261	"
Z22.30—1941	None	—
Z22.31—1946	"	—
Z22.32—1941	"	—
Z22.33—1941	"	—
Z22.34—1944	"	—
Z22.35—1930	"	—
Z22.36—1944	"	—
Z22.37—1944	"	—
Z22.38—1944	JAN-S-424	Approved
Z22.39—1944	None	—
Z22.40—1946	"	—
Z22.41—1946	JAN-S-424	Approved
Z22.42—1946	No number assigned	In preparation
Z22.43—1946	" " "	" "
Z22.44—1946	" " "	" "
Z22.45—1946	" " "	" "
Z22.46—1946	None	Under consideration for JAN-S-424
Z22.47—1946	"	" " "
Z22.48—1946	"	" " "
Z22.49—1946	"	" " "
Z22.50—1946	JAN-S-424	Approved
Z22.51—1946	None	—
Z22.52—1946	"	—
Z22.53—1946	"	Under consideration for JAN-S-424
Z22.54—1946	No number assigned	In preparation

(*Table Continued*)

AMERICAN WAR STANDARDS

ASA standard	Applicable government specification	Specification status
Z52.1—1944	JAN-P-49	Approved
Z52.2—1944	No number assigned	In preparation
Z52.3—1944	JAN-P-55	Approved
Z52.6—1944	No number assigned	In preparation
Z52.7—1944	" " "	" "
Z52.10—1944	" " "	" "
Z52.12—1944	JAN-M-58	Approved
Z52.14—1944	None	—
Z52.18—1945	JAN-C-250	Approved
Z52.19—1944	None	Under consideration for JAN-S-424
Z52.20—1944	JAN-S-424	Approved
Z52.21—1944	None	—
Z52.22—1944	"	—
Z52.29—1945	"	—
Z52.30—1944	"	—
Z52.31—1945	"	Under consideration for JAN-S-424
Z52.33—1945	JAN-R-214	Approved
Z52.35—1944	None	—
Z52.37—1944	"	—
Z52.38—1945	"	—
Z52.41—1945	(See Z22.29)	—
Z52.42—1945	None	—
Z52.43—1944	Fed W-L-122	Approved
Z52.44—1945	None	—
Z52.45—1945	"	—
Z52.46—1945	"	—
Z52.47—1946	JAN-S-424	Approved
Z52.48—1946	JAN-S-424	"
Z52.50—1946	JAN-S-424	"
Z52.51—1946	JAN-S-424	"
Z52.53—1945	None	Under consideration for JAN-S-424
Z52.55—1945	"	—
Z52.60—1945	"	—
Z52.61—1945	"	—
Z52.62—1946	"	—

AMERICAN WAR STANDARDS (*Continued*)

ASA standard	Applicable government specification	Specification status
Z52.63—1946	"	—
Z52.65—1946	"	—
Z52.68—1946	"	—
Z52.69—1945	"	—
Z52.70—1945	"	—

NOTE: 1. Symbol JAN—Joint Army Navy Specification.
" FED—Federal Specification.
2. In some cases, individual standard pertaining to methods of test are included in equipment specifications, *e.g.*, Z52.45 is included in the four JAN screen specifications.

Bibliography

Hyndman, D. E., "War Standards for Motion Picture Equipment and Processes," *JSMPE, 42,* 211 (Apr. 1944).

JSMPE, 43, July 1949, papers by D. E. Hyndman, J. W. McNair, S. L. Chertok, M. R. Boyer, A. G. Zimmerman, J. M. Whittenton, M. G. Townsley, M. G. Townsley, and M. G. Townsley.

Zimmerman, A. G., "War Standards for Photographic Equipment Speed Military Instruction," *JSMPE, 43,* 115 (Aug. 1944).

SUBJECT INDEX

D

E